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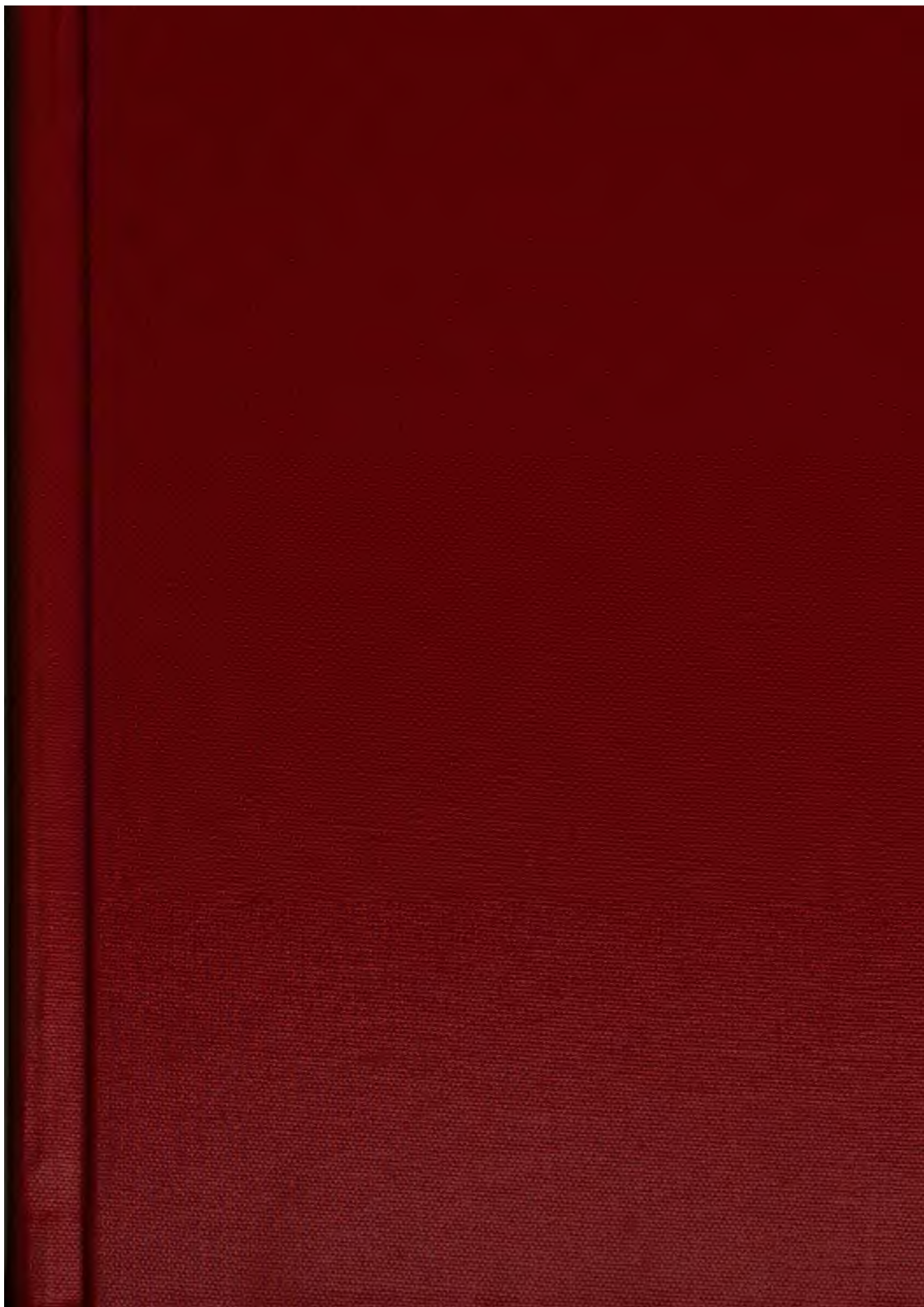
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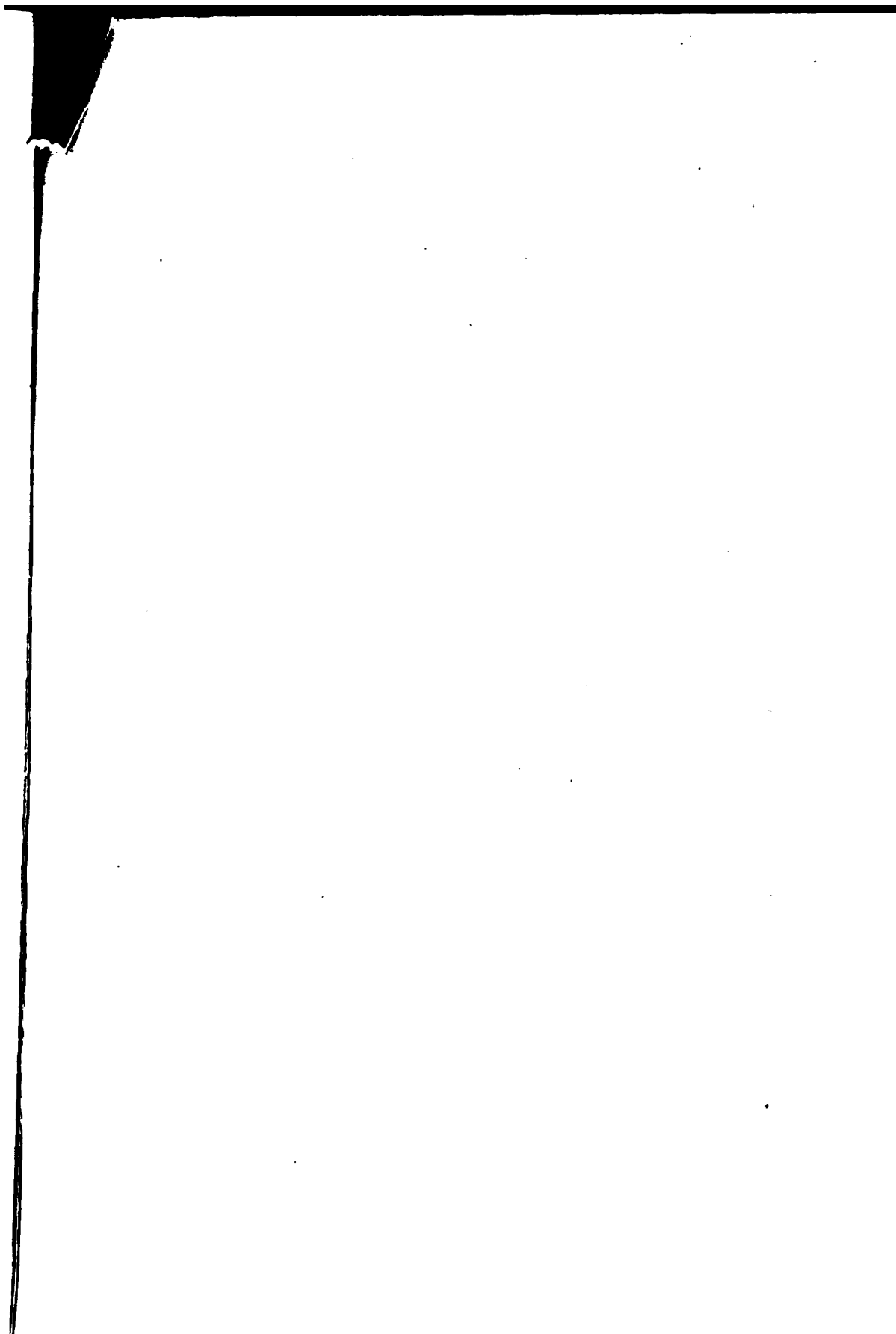


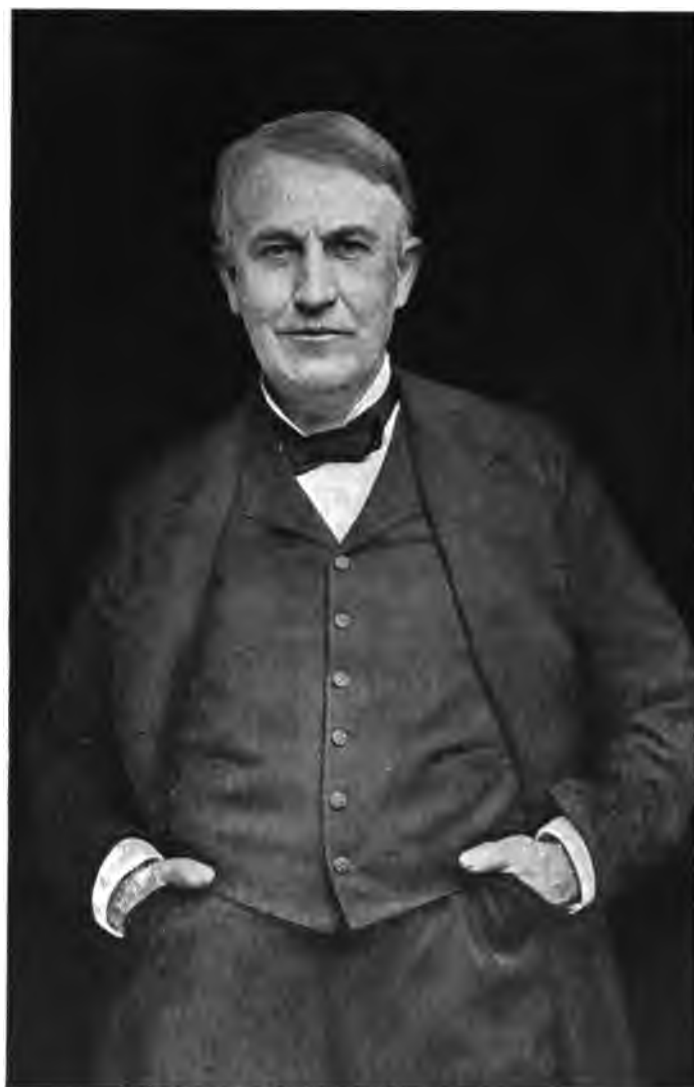


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Grateful acknowledgment is here made also for the invaluable co-operation of the foremost engineering firms, in making these volumes thoroughly representative of the best and latest practice in the design and construction of steam and electrical machines; also for the valuable drawings and data, suggestions, criticisms, and other courtesies.

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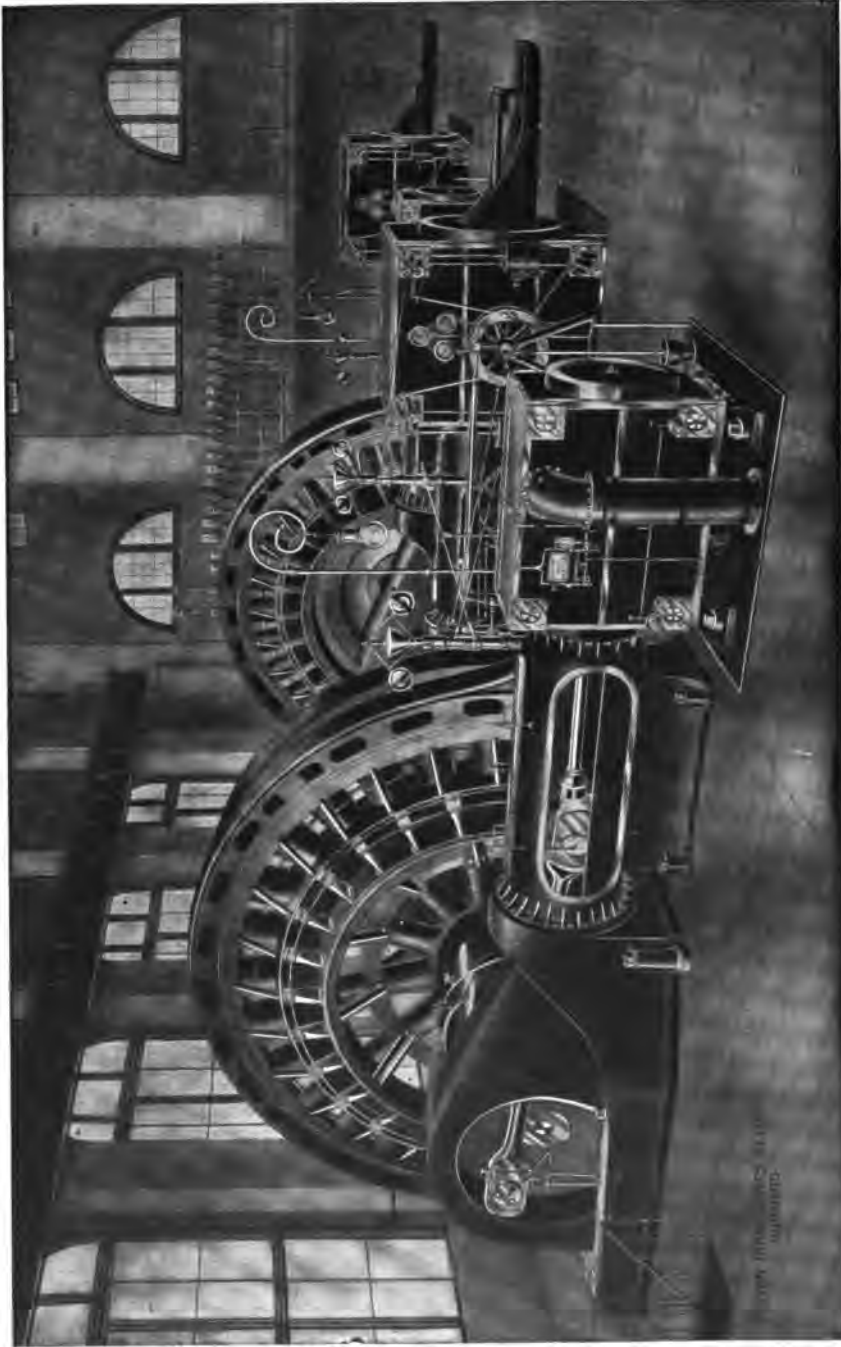
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THE rapid advances made in recent years in all lines of engineering, as seen in the evolution of improved types of machinery, new mechanical processes and methods, and even new materials of workmanship, have created a distinct necessity for an authoritative work of general reference embodying the accumulated results of modern experience and the latest approved practice. The Cyclopedia of Engineering is designed to fill this acknowledged need.

¶ The aim of the publishers has been to create a work which, while adequate to meet all demands of the technically trained expert, will appeal equally to the self-taught practical man, who may have been denied the advantages of training at a resident technical school. The Cyclopedia not only covers the fundamentals that underlie all engineering, but places the reader in direct contact with the experience of teachers fresh from practical work, thus putting him abreast of the latest progress and furnishing him that adjustment to advanced modern needs and conditions which is a necessity even to the technical graduate.

¶ The Cyclopedia of Engineering is based upon the method which the American School of Correspondence has developed and successfully used for many years in teaching the principles and practice of Engineering in its different branches.

¶ The success which the American School of Correspondence has attained as a factor in the machinery of modern technical and scientific education is in itself the best possible guarantee

for the present work. Therefore, while these volumes are a marked innovation in technical literature—representing, as they do, the best ideas and methods of a large number of different authors, each an acknowledged authority in his work—they are by no means an experiment, but are, in fact, based on what has proved itself to be the most successful method yet devised for the education of the busy man. The formulæ of the higher mathematics have been avoided as far as possible, and every care exercised to elucidate the text by abundant and appropriate illustrations.

¶ Numerous examples for practice are inserted at intervals; these, with the text questions, help the reader to fix in mind the essential points, thus combining the advantages of a textbook with those of a reference work.

¶ The Cyclopedia has been compiled with the idea of making it a work thoroughly technical yet easily comprehended by the man who has but little time in which to acquaint himself with the fundamental branches of practical engineering. If, therefore, it should benefit any of the large number of workers who need, yet lack, technical training, the publishers will feel that its mission has been accomplished.

¶ Grateful acknowledgment is due the corps of authors and collaborators—engineers and designers of wide practical experience, and teachers of well-recognized ability—without whose co-operation this work would have been impossible.



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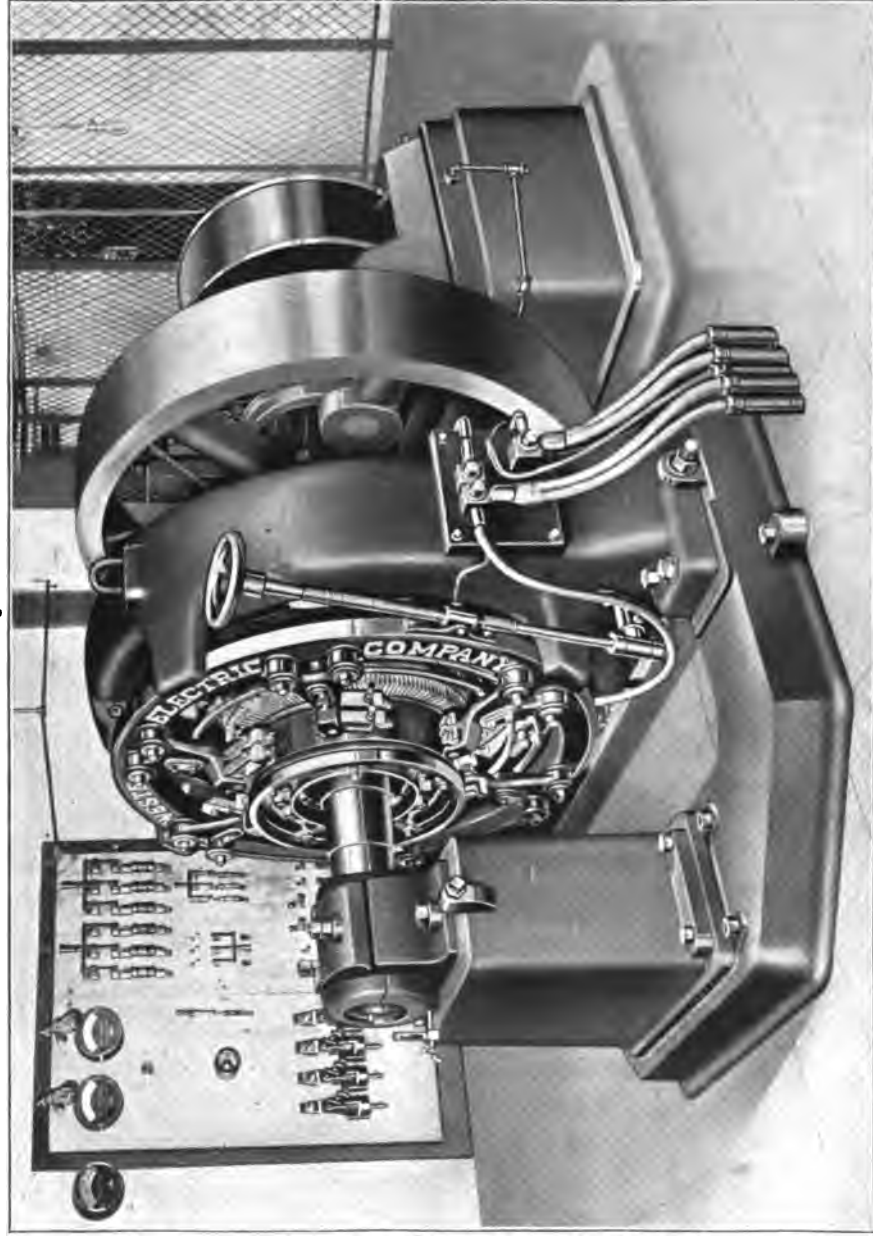
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DYNAMO-ELECTRIC MACHINERY

PART I

PRINCIPLES OF DIRECT-CURRENT DYNAMOS

A *dynamo-electric machine* is one which converts mechanical into electrical energy, or *vice versa*, by means of the relative motion of a conductor carrying an electric current, and an interlinked magnetic field. When the conversion is from mechanical to electrical energy, the machine is called a *generator*; and when the conversion is from electrical to mechanical energy, the machine is called a *motor*. In order fully to understand the design and construction of these machines, it will first be necessary to consider the principles which govern their action.

Magnetic Field. It was early found that pieces of a certain kind of iron ore were capable of attracting bits of iron. From the name

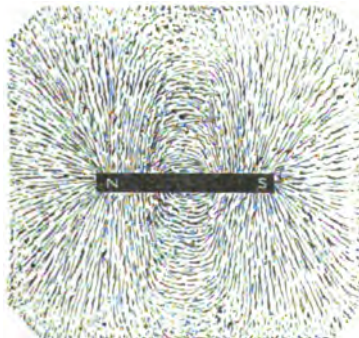


Fig. 1. Magnetic Field around a Bar Magnet.

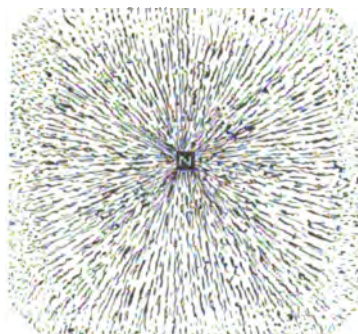


Fig. 2. Magnetic Field around One Pole of a Bar Magnet.

of the country in which this peculiar oxide of iron was first found, came the name of articles made of it—i.e., *magnets*, from “Magnesia,” in Asia. This oxide of iron is Fe_3O_4 , commonly called *Magnetite*.

If one of these magnets shaped as a straight bar is held under a piece of cardboard upon which iron filings are sprinkled, it will be

found that the filings settle down in curved lines forming a magnetic figure, the general form of which is shown in Fig. 1. When one of the poles of the magnet is held toward the cardboard, the filings will arrange themselves as shown in Fig. 2. These experiments show

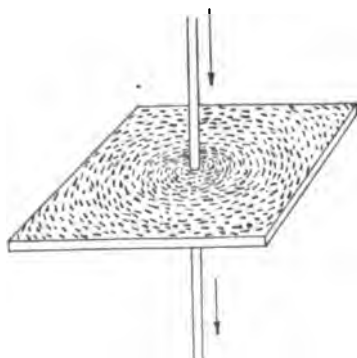


Fig. 3. Magnetic Field around a Current-Carrying Conductor.

that the medium surrounding a magnet is in a state of stress, the space so affected being called a *magnetic field*. The influence of a magnet is supposed to extend in all directions indefinitely; *but as the force due to the magnet varies inversely as the square of the distance from it*, the effect is rendered practically negligible beyond a comparatively limited area.

When a conductor carrying a current of electricity is passed through a piece of cardboard with iron filings sprinkled on the board as before, we see (Fig. 3) that the filings arrange themselves in curved lines similar to those of Fig. 2; while, if the return circuit of the conductor be also poked through the card, the filings assume the alignment shown in Fig. 4. From the similarity of the phenomena, it may be concluded that a conductor carrying an electric current is surrounded by a magnetic field whose strength is a direct function of the current. This was first noted by Oersted, who in 1820 observed that a compass needle was deflected when placed near a conductor carrying a current of electricity, the direction of motion of the needle depending upon the direction of flow of the current.

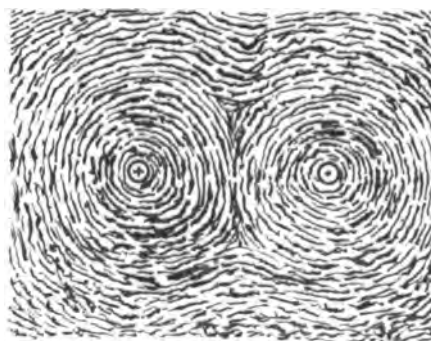


Fig. 4. Magnetic Field around Conductor and Return Circuit.

Lines of Magnetic Force. The magnetic figures in the previous paragraph indicate that the stresses in the medium surrounding a

magnet or current-carrying conductor follow certain definite lines, the lines showing the direction of stress at any point. These are called *lines of magnetic force*. If, in addition, there be drawn as many lines per square centimeter cross-section of the field as there would be dynes of force acting upon a unit magnetic pole* placed at that point, then the total number of lines of magnetic force represents the *magnetic flux* through that cross-section; and the lines per square centimeter, the *flux-density*.

Solenoids. Now, suppose that a wire is bent in the form of a circular loop as in Fig. 5, and furthermore suppose that a current is traversing the conductor in the direction indicated. Then, according to a rule suggested by Maxwell,

"The direction of the current and that of the resulting magnetic force are related to one another, as the rotation and travel of an ordinary (*i. e.*, right-handed) screw."

Consequently the lines of magnetic force would surround the loop in the manner shown. The field of such a loop, on being explored with a compass needle or filings, will be seen to retain the general character of the field surrounding a straight conductor; and consequently all the lines will leave by one face and return by the other, the entire number passing through the loop. Hence one face of the loop will be equivalent to the north pole of a magnet, and the opposite face will correspond to the south pole. In fact the loop will act exactly as if it were a thin disc magnetized perpendicularly to its plane.

By placing side by side several of these current loops, with their transverse axes in the same straight line, there is formed a *solenoid* (Fig. 6); and exploration of the resulting field by any of the above methods shows that the lines of force pass right through the interior of the solenoid, leaving by one end and returning by the opposite end as suggested by Maxwell's rule. A cylinder of soft iron inserted in the space within the solenoid will be found to act strongly as a

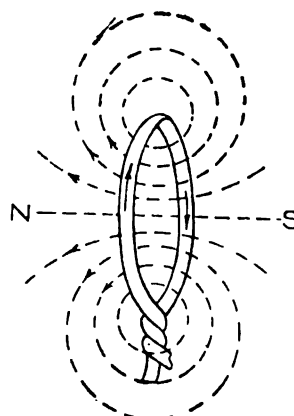


Fig. 5. Magnetic Field around a Conducting Loop.

* A *unit magnetic pole* is one which, when placed at a distance of one centimeter from a similar pole, in vacuum or practically air, exerts upon it a force of one dyne.

magnet when the current flows around the solenoid; but if the current is interrupted, the magnetic effect almost disappears. Reversal of the current will be found to reverse the polarity of the core, while increasing the current augments the magnetic strength of the coil.

Toroid. Bend the solenoid of the previous paragraph around until its ends meet; or produce the same winding by turning insulated wire around an endless ring core of circular cross-section. The arrangement thus produced will be a *toroid*, commonly called *Faraday's ring*; and if the wires are wound closely and uniformly over the whole periphery, the lines of force will be closed curves whose paths lie

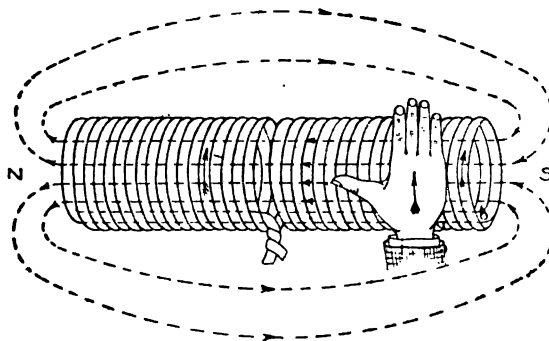


Fig. 6. Arrangement of Conductive Loops Forming a Solenoid, with Surrounding Magnetic Field.

entirely within the turns; consequently there are no external poles—a unique electromagnetic condition.

Magneto-Electric Induction. Thus far the condition of the magnetic field has been

determined by means of filings or magnets; but neither of these methods can be used to explore the interior of an iron-cored toroid. It is possible, however, to employ for this purpose the principles of *magneto-electric induction* discovered by Faraday in 1831. One of the laws governing this phenomenon, first enunciated by Neumann in such manner as to permit determination of the electromotive force developed, is as follows:

"Whenever the flux interlinked with a circuit is varying, there is an e. m. f. acting around the circuit, proportional to the time rate of change of the flux, the positive direction of the e. m. f. and the positive direction of the flux passing through the circuit being related to each other as are the rotation and travel of a right-handed screw. That is, if a circular loop is moved in the field of a magnet in such a way that it does not enclose the same amount of flux at any two successive instants, then there is induced in the loop an e. m. f. whose value is proportional to the change of enclosed flux per unit time. A similar effect will be obtained by keeping the loop fixed, and moving the magnet."

We thus have a way to investigate the condition of the field within the solid-cored toroid previously mentioned. Suppose a loop of insulated wire to be placed around the toroid in Fig. 7, and suppose the terminals of this loop to be led to a ballistic galvanometer (that is, an instrument which will measure current impulses). Then if the magnetizing coil of the toroid be energized by passing a current through it, the galvanometer will give a sudden throw the instant the current is started. Similarly, when the circuit is broken and the current ceases, the galvanometer indicates the passage of another current impulse through the loop, the deflection, however, being in the opposite direction.

The loop is next removed from the toroid and placed in front of an iron-cored solenoid which can be energized or de-energized at will by closing or opening a switch, and it will be found that similar effects are produced. Let, now, the electromagnet be energized and de-energized periodically, and the loop or exploring coil be turned so that its axis occupies every possible direction in space, the center of the loop remaining stationary throughout. It will be found that when this axis is in one particular plane, no impulse will pass through the exploring coil when the exciting current of the electromagnet is caused to flow, to cease, or to reverse. From what has been explained previously, we see that in this case the loop interlinks with no flux, hence its plane must be parallel to the direction of the flux. Also we see that when the plane of the loop takes any other position, the flux interlinked with it depends upon the relation between the plane of the loop and the direction of the flux. If we call the angle between the direction of the flux and the axis of the loop α , the flux enclosed by the loop for any given value of the exciting current of the electromagnet will be proportional to the cosine of α . The quantity we are thus investigating is a directed quantity, and may therefore be represented by a vector.

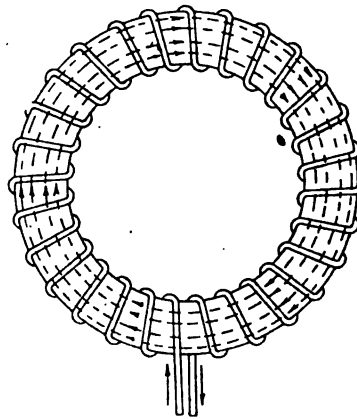


Fig. 7. Lines of Force in Toroid Surrounded by a Magnetizing Coil.

Lines of Magnetic Induction. This quantity is called the *magnetic induction* or *flux*, and its direction at any point is defined as that of the axis of the loop when in the position giving the greatest inductive effect on energizing or de-energizing the electromagnet. Its direction is also defined by Neumann's law. If, now, a curve be drawn following the direction of the flux, this curve will be a line of magnetic induction. The flux and flux-density are defined in a way precisely similar to magnetic force.

Relation between Magnetic Force and Magnetic Induction. In the earliest of Faraday's experiments with solenoids, he found that the flux through any of these was much greater when iron was inserted than when air or wood was enclosed by the coil of wire. He ascribed this peculiar circumstance to the greater "conducting power of the magnetic medium for lines of force." Lord Kelvin introduced the phrase *magnetic permeability* for this property of magnetic materials, and it is defined as the ratio between the magnetic induction (B) produced in the medium and the magnetic force (H) to which that induction is due; i. e.,

$$\mu = \frac{B}{H}.$$

Magnetic Permeability. The precise notion now attached to this term is that of a numerical coefficient, and it is analogous to electrical conductivity. Its value is dependent upon the character of the substance and the magnetizing force or m. m. f. applied to the substance. For vacuum its value is unity; for air it is practically unity; for magnetic materials it is greater than 1 and may reach 2,500 for soft iron; while for diamagnetic materials it is slightly less than 1. The permeability of such non-magnetic materials as silk, cotton, and other insulators, also of brass, copper, and other non-magnetic metals, is taken as unity, being practically the same as for air.

The permeability of iron, however, varies very greatly with the degree to which it has been magnetized. In all kinds of iron (after passing the initial stage mentioned below), the magnetizability of the material becomes diminished as the actual magnetization is pushed further; in fact, there is a tendency to magnetic saturation. In other words, when the piece of iron has been magnetized up to a certain degree, it becomes less permeable to further magnetization; and although actual saturation is never reached, there is a limit

beyond which the magnetization cannot be increased with practical advantage. This is shown in Fig. 8, which represents the permeability curve of a sample of good iron or steel as used in dynamo magnet construction. The practical limit of the flux-density (B) in good wrought iron and in mild steel, is about 20,000 lines of magnetic induction per square centimeter; and in cast iron the saturation limit in practice is about 12,000 lines per square centimeter. In square-inch units these limits are, for wrought iron and mild steel, about 125,000 or 130,000 lines per square inch; and for cast iron, about 70,000 lines per square inch.

Magnetic Circuit. Returning to the toroid of Fig. 7, we see that the lines pass through the interior of the toroid, forming a closed magnetic circuit. Now, it is found that the total flux within the toroid is equal to the ratio between the magnetomotive force acting around the magnetic circuit and the reluctance of that circuit; that is

$$\phi = \frac{\text{m. m. f.}}{R},$$

in which,

ϕ = Total flux;

m. m. f. = Magnetomotive force;

R = Magnetic reluctance.

Magnetomotive Force. By this term is meant the total magnetizing power of an electric current circulating in a coil. It is found, when a current flows in a wire wound several times around a core, as in Fig. 9, that the magnetizing power is proportional both to the strength of the current and to the number of turns of wire. The magnetizing power is independent of the size of the wire or the coils and of their shape, remaining also the same whether the spirals are close together or wide apart. Hence if T be the number of turns in the coil, and I be the current in amperes passing through each turn, the magnetomotive force is,

$$\text{m. m. f.} = \frac{4}{10} \pi \times IT = 1.257 IT.$$

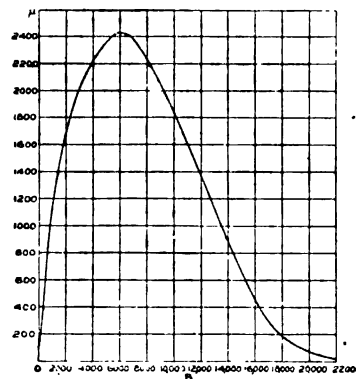


Fig. 8. Permeability Curve of Iron or Steel Used in Dynamo Magnet Construction.

A straight conductor carrying an electric current of which the return is very distant, as in Fig. 10, is surrounded by circular concentric lines. Taking one of these lines at a distance r centimeters

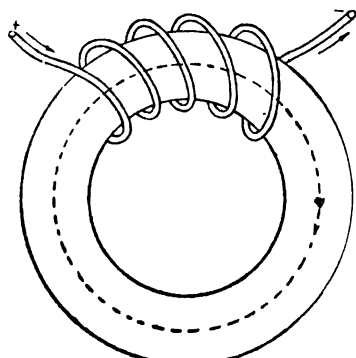


Fig. 9. Showing Relation between Magnetizing Power of a Coil and Its Number of Turns.

from the axis of the wire, which we suppose to be carrying I amperes (that is, $\frac{I}{10}$ units of current in C.

G. S. electromagnetic units), the intensity of the field at any point at radius r has the uniform value $\frac{2I}{10r}$, and its direction is that of the given line, of which the length is $2\pi r$. Hence the total force around the circle of radius r concentric with the axis of the conductor, will

be the product of the force at any point of its circumference into the length of this circumference; *i. e.*,

$$\frac{2I}{10r} \times 2\pi r = \frac{4\pi}{10} I.$$

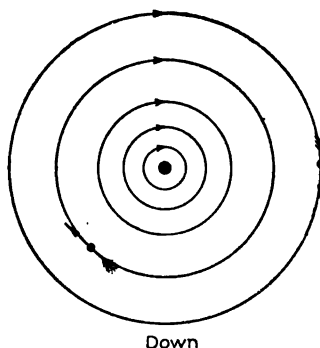
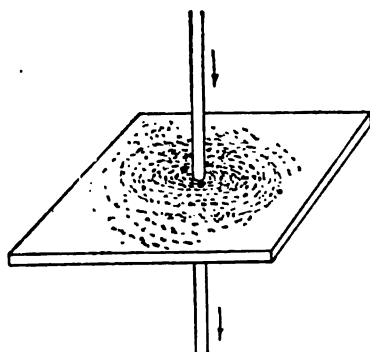


Fig. 10. Illustrating Variation in Intensity of Magnetic Field Surrounding a Conductor with Distant Return.

And if the single wire be replaced by T turns, the force will be T times as large, or $\frac{4\pi}{10} I T$, $I T$ being called the *ampere-turns*.

Reluctance. We have seen from the equation of the magnetic circuit, that the total flux is inversely proportional to the reluctivity

of the materials of which it is composed; it is directly proportional to the permeability which is the reciprocal of the reluctivity. The reluctance or magnetic resistance of a circuit is therefore obviously proportional to its length, and inversely proportional to its area of cross-section and its permeability; that is,

$$R = \frac{l}{\mu A}$$

In designing electromagnets, before calculations can be made as to the size of the iron core required, it is necessary to know the magnetic properties of that particular iron; for it is obvious that inferior permeability demands a larger cross-section to obtain a given flux, or inferior permeability will require more turns of copper wire to be used.

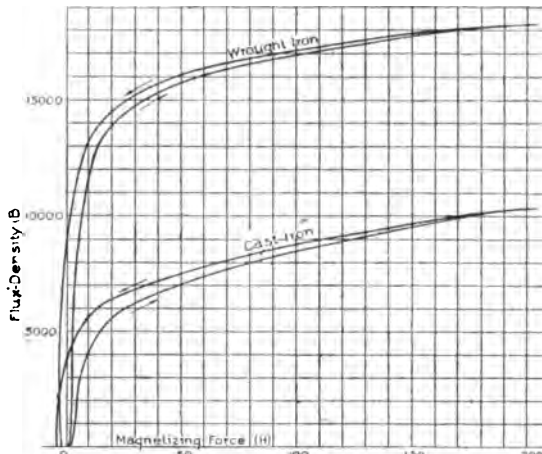


Fig. 11. Magnetization Curves of Wrought Iron and Cast Iron.

Magnetization Curves. A convenient method of studying the magnetic facts respecting any particular brand of iron, is to plot as a diagram the *curve of magnetization*—that is, the curve representing the relation between the magnetic force plotted horizontally, and the magnetic induction plotted vertically.

The upper curve in Fig. 11 gives the behavior of annealed wrought iron. The ascending curve shows the relation between the intensity of the magnetizing force H and the flux-density B during the process of increasing the magnetizing force from zero to about 210 units; and the descending line shows the same relation during the process of decreasing the magnetizing force to zero, and then reversing it so as to remove the residual magnetic lines. The lower curve shows the behavior of grey cast iron.

Every sample of iron will show a similar set of results, which can

be plotted in the form of a curve that is characteristic. The curves for cast iron and hard steel always have lower values than those for wrought iron or mild steel. In addition, it will usually be noted that when a fresh piece of iron or steel is subjected to a gradually increasing magnetizing force, the lowest part of the curve presents near its origin a small concavity (see Fig. 11), showing that under certain magnetizing forces the permeability is greater than at the initial stage. This concavity is more pronounced in the case of hard iron and steel than in the case of soft iron, but the curves differ in detail even in different specimens of the same sort of iron.

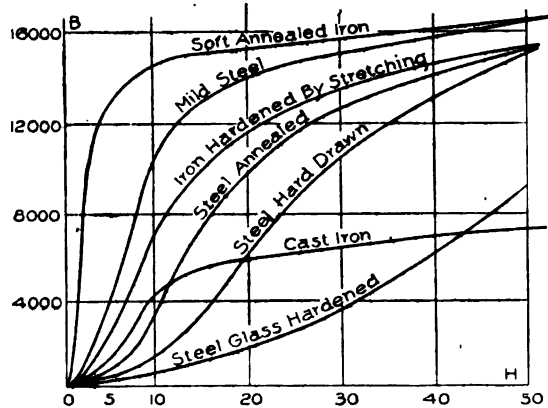


Fig. 12. Magnetization Curves of Various Irons and Steels Used in Dynamo Construction.

and steel than in the case of soft iron, but the curves differ in detail even in different specimens of the same sort of iron.

Fig. 12 gives a comparative idea of the relation between the magnetic properties of the various irons and steels used in dynamo manufacture.

Effect of Air-Gap in Magnetic Circuit. Thus far we have considered the magnetic circuit as made up of a solid, endless ring of iron. But suppose it to be built up partly of iron and partly of some non-magnetic material, as air or copper. We then have, as the total reluctance of the magnetic circuit, the sum of the reluctances of the various parts of the circuit. For example, if we have a ring made up of l_1 centimeters of iron and l_a centimeters of air, the reluctance of this magnetic circuit would be,

$$R = \frac{l_1}{\mu_1 A_1} + \frac{l_a}{\mu_a A_a},$$

in which μ and A are respectively the permeability and cross-sectional area of the materials denoted by the subscripts.

It follows, then, that the total flux of such a circuit would be,

$$\phi = \frac{0.4 \pi I T}{\frac{l_1}{\mu_1 A_1} + \frac{l_a}{\mu_a A_a}},$$

in which $I T$ represents the ampere-turns and $.4 \pi = 1.257$ as before.

Since the magnetic permeability of air is constant and practically equal to unity, we see that an air-gap or its equivalent introduced into a magnetic circuit previously consisting of iron, will increase the m. m. f. required to produce the same flux as before, due to the inferior permeability of the non-magnetic portion.

S. P. Thompson makes this plain by a graphical method as follows:

"The curve OcC (Fig. 13) represents the relation between the number of magnetic lines in an iron bar and the ampere-turns ($= Hl \div 1.257$) needed to force these magnetic lines through the iron. For example, to reach the height c , the excitation has to be of the value represented by the length Ox_1 . On the same diagram the line ObB represents the relation between the magnetic flux across the air-gap and the ampere-turns of current (stream) required to force this flux across. If the gap were 1 centimeter long, 0.795 ampere-turn would produce the field $H = B = 1$. In the present case the gap is supposed to be shorter than 1 centimeter, the line sloping up at such an angle that the length Ox_2 represents the ampere-turns requisite to bring the magnetic flux up to b , the same height on the scale as c . The total amount of excitation required to force these magnetic lines through air and iron will (neglecting leakage) be the sum of the separate amounts. The point x_3 is chosen so that Ox_3 is equal to the sum of Ox_1 and Ox_2 , or that the distance of the point r from the vertical axis is equal to the sum of the respective distances of c and b . If the same thing is done for a large number of corresponding points, the resultant curve OrR may be constructed from the two separate curves. It will be seen, then, that in general the presence of a gap in the magnetic circuit has the effect of causing the magnetic curve to rake over, the initial slope being determined by the air-gap."

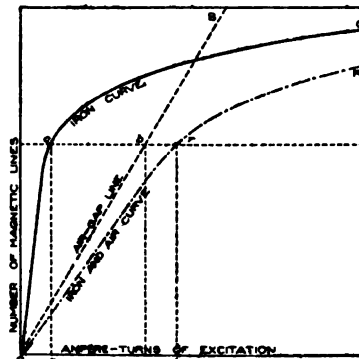


Fig. 13. Graphical Method of Showing Effect of Air-Gap in a Magnetic Circuit.

Effect of Joints in the Magnetic Circuit. Ewing* tried the effect of different numbers of joints in the iron of a magnetic circuit for various magnetizing forces, his results being given in Fig. 14. They refer to a bar of wrought iron cut across, first into two pieces, then into four, and finally into eight pieces. He also found that when the faces of a cut were carefully surfaced up to true planes, the disadvantageous effects of the cut were considerably reduced, and under

* "Magnetic Induction in Iron and Other Metals," London, 1893, pages 308 to 373.

considerable pressure applied externally almost vanished. An ordinary joint is equivalent to an air-gap of about .005 cm. = .002 inch.

Effects of Heat. When iron is raised to 600°C., it begins to lose its magnetic properties; and, if the temperature is increased to 780°C., they entirely disappear. At temperatures between 0°C. and 100°C., various other effects have been noted, such as *aging*—that is, an increase in the hysteresis. In dynamos, however, these effects are

practically negligible, since the working temperature should not exceed 75°C.

Residual Magnetism. It has been found, when the magnetizing forces have been removed from a specimen of iron, that it still exhibits some phenomena of magnetism. This residual magnetism depends for its magnitude upon the character of the iron or steel, being greater in the harder grades than in the softer ones.

Referring to Fig. 11, it will be seen that when a specimen of wrought iron was magnetized to a

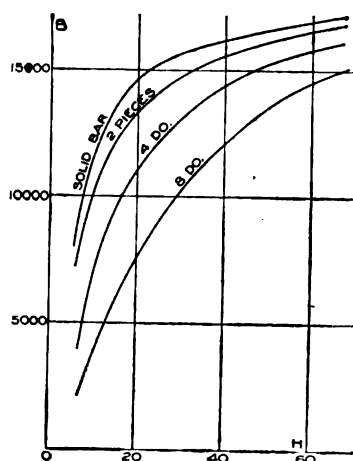


Fig. 14. Curves Showing Effects of Joints in Magnetic Circuit.

high flux-density, and the m. m. f. then reduced to zero, the flux-density diminished only to about 7,300 lines per square centimeter, the descending curve of magnetization being above the ascending one. The name *remance* is given to the lines per square centimeter so remaining. Furthermore, in order to remove this remance, it is necessary to apply a certain negative magnetizing force, termed by Hopkinson the *coercive force*. It varies in magnitude from 2 for soft wrought iron, to about 80 units or more for hard steel.

Effects of Cycles of Magnetization. This tendency of the magnetic effects to lag behind the forces producing them has been named by Ewing *hysteresis*, and is best studied by subjecting the iron specimen to one or more complete cycles of magnetization. For instance, suppose the m. m. f. applied to a piece of iron to be increased gradually from zero to a maximum value, then decreased through zero to an equal negative maximum, and finally to reverse and return

through zero to the positive maximum value. The magnetic changes for such a complete cycle are shown in Fig. 15 for specimens of iron and steel respectively.

The process as shown by the diagram, is started with the flux-density and m. m. f. at zero. The latter is then increased to about 60 units, in the case of the piece of iron, the resulting flux-density being 16,000. The m. m. f. is then reduced to zero, the flux-density only decreasing to 12,800. At a m. m. f. of -3 , the flux-density is brought to zero; that is, -3 is the coercive force, and 12,800

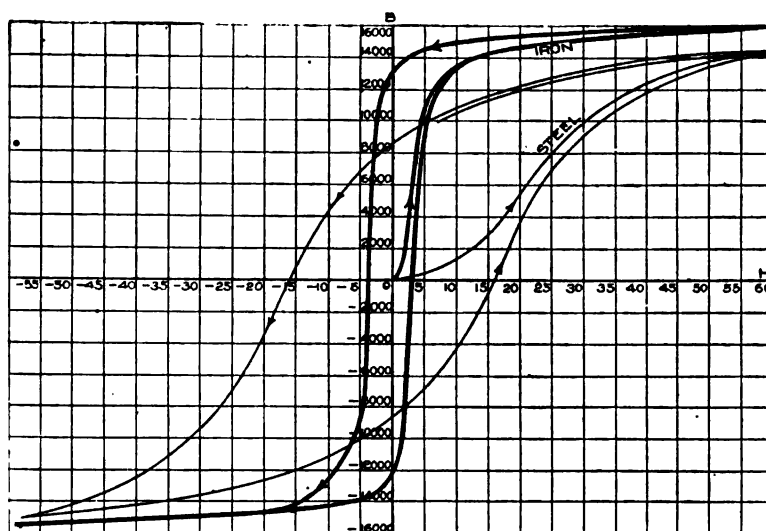


Fig. 15. Curves Showing Magnetic Changes in Iron and Steel Due to Complete Cycles of Magnetization.

the remanence. With a m. m. f. of -60 , the flux-density is $-15,500$; and varying the m. m. f. from this point to zero, leaves the specimen with a flux-density of $-12,000$. Further increasing the m. m. f. until the flux-density becomes zero, the final m. m. f. is found to be $+3$. From this point the m. m. f. is increased to its former maximum value, this ascending curve differing a little from the first. Thus we see that when a specimen of magnetic material is put through a complete magnetic cycle, the coincident values of the m. m. f. and the flux-density form a close curve. The area thus enclosed has been shown by Warburg and Ewing to represent the energy wasted as

TABLE I
Hysteretic Constants for Different Materials

MATERIAL	HYSTER- ETIC CON- STANT η	MATERIAL	HYSTER- ETIC CON- STANT η
Very soft iron wire.	.002	Soft annealed cast steel. .	.008
Very thin soft sheet iron. .	.0024	Soft machine steel.	.0094
Thin good sheet iron.	.003	Cast steel.	.012
Thick sheet iron.	.0033	Cast iron.	.016
Most ordinary sheet iron. .	.004	Hardened cast steel.	.025
Transformer cores.	.0045		

heat in the material, when the specimen is put through a complete cycle; and its value depends upon both the character of the material, and the degree of magnetization, being greater for hard steel than for soft iron with the same range of magnetization.

Iron, when placed in an alternating magnetic field, is not only subjected to the hysteresis phenomena above considered, but it also becomes subjected to a set of parasitic electrical currents. These tend further to heat the iron, and are called *Foucault* or *eddy currents*; their path, by Maxwell's law, is perpendicular to the direction of the flux. Their value may be lessened by increasing the resistance of their path—that is, by *laminating the iron in a direction parallel to the direction of the flux and perpendicular to the path of these currents*, each sheet of iron being insulated from its neighbors. In practice, these laminæ vary from about 15 to 25 mils (0.015 inch to 0.025 inch) in thickness.

Calculation of Heat Waste in Iron Cores. From consideration of a great many tests of hysteretic losses, Dr. C. P. Steinmetz proposed the following law connecting the hysteresis loss h in ergs per cubic centimeter per cycle and the maximum flux-density B attained during a cycle:

$$h = \eta B^{1.6},$$

wherein η is a coefficient called the *hysteretic constant*, depending for its value upon the quality of the material. Some of these constants are given in Table I for ordinary frequencies. This law is practically true for all cycles ranging up to 200 per second.

By applying the proper transformation factors, the Steinmetz formula reduces to:

$$W_h = 0.83 \times \eta \times f \times B^{1.6} \times 10^{-7},$$

wherein

W^h = Hysteresis loss in watts per cubic inch of iron;

f = Frequency in cycles per second;

B = Flux-density in lines per square inch.

In Fig. 16 are given graphically the hysteresis losses in watts per cubic inch of iron per cycle per second, with various hysteretic constants.

Besides the hysteretic loss in iron cores, there is also the eddy-current loss, which varies directly as the square of the thickness of the iron laminæ, as the square of the maximum flux-density, and as

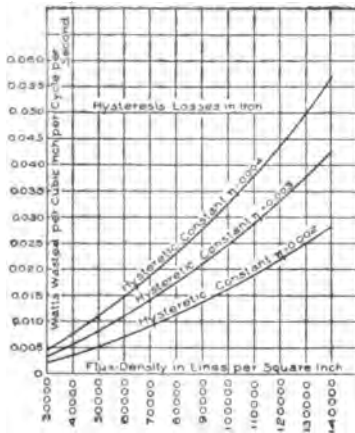


Fig. 16. Curves Showing Hysteresis Losses in Iron with Various Hysteretic Constants.

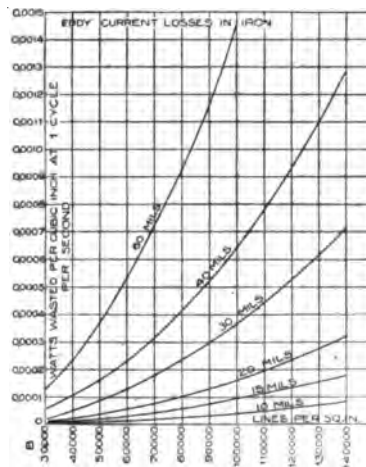


Fig. 17. Curves Showing Eddy-Current Losses in Iron of Varying Thickness under Varying Flux-Density.

the square of the frequency. The formula obtained by calculation and found to agree closely with practice, is:

$$W_e = 40.6 \times t^2 \times B^2 \times n^2 \times 10^{-12},$$

wherein

W_e = Watts loss due to eddy currents per cubic inch of iron;

t = Thickness of the iron plates, in inches; and the other symbols have the meanings previously assigned.

Fig. 17 exhibits values of W_e graphically for various thicknesses of iron over wide ranges of flux-density at one cycle per second.

The sum of these losses for any electrical machine is called for brevity the *iron-losses* of that machine. Calculations for actual machines will be given later.

Rotational Hysteresis. When a piece of iron is rotated in a magnetic field, it passes through a magnetic cycle, but in a way far different from that which has been described. Mordey found the losses to be slightly lower for rotation than for reversal; while Bailly went further and showed (Fig. 18) that the former loss was slightly greater than the latter for flux-densities up to 15,000 lines per square centimeter, but that beyond this point the loss due to rotation rapidly diminished with increase in flux-density.

Owing, however, to eddy-current losses, the flux-densities in those parts of electrical machines which rotate in a fixed magnetic

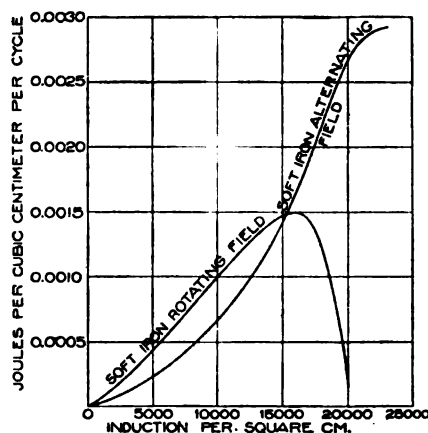
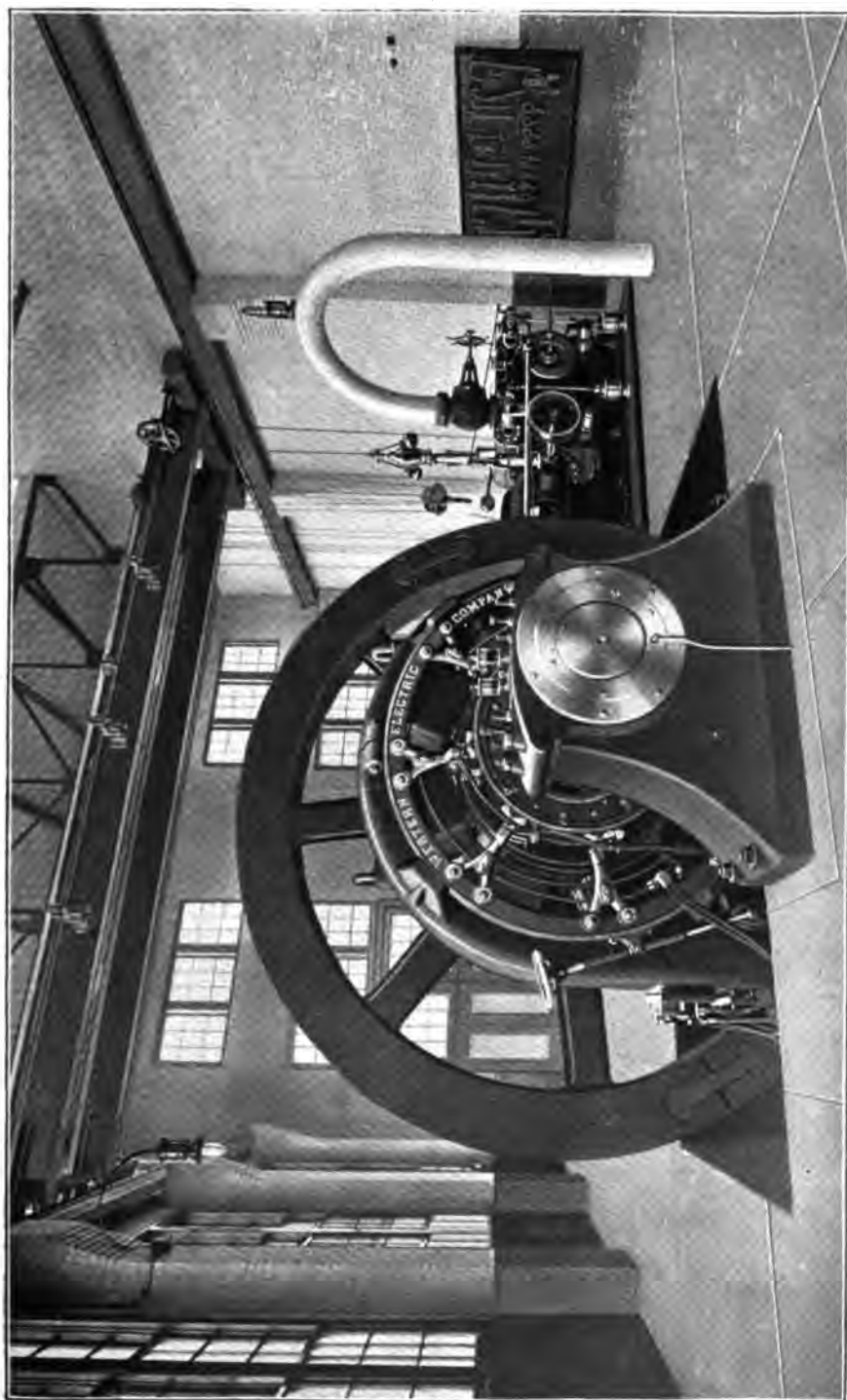


Fig. 18. Curves Showing Relation between Hysteresis Losses in Rotating and Alternating Fields.

field are not allowed to exceed 15,000 lines per square centimeter ($15,000 \times 6.45$ lines per sq. in.), except in the armature teeth of direct-current machines. We may therefore neglect this difference, as is usual in practice, and may calculate both kinds of hysteresis loss by the formula previously given. According to Ewing, this rotation loss is *molecular magnetic friction* and not true hysteresis, because the magnetization does not necessarily lag behind the m. m. f.

Miscellaneous Magnetic Effects. *Retardation of Magnetization.* It has long been known that, owing to the eddy currents produced in the iron cores of electromagnets, the magnetism of the inner part builds up less rapidly than that of the outer parts. Similarly, when the m. m. f. is cut off, the inner part of the core retains its magnetism longer than the outer parts. In dynamos with large field-magnets, several minutes may elapse before the field will build up or change, and Hopkinson has shown that the retardation varies as the square of the linear dimensions of the core.

Magnetic Creeping. Ewing found that when a steady m. m. f. was applied to a specimen of iron, and the magnetism measured at intervals, the flux-density kept continually creeping up although



THREE-WIRE D. C. GENERATOR IN THE SHOPS OF THE KANSAS CITY SOUTHERN RY. CO.
Western Electric Co., Chicago, Ill.

the m. m. f. was absolutely constant. He named this *viscous hysteresis*; but it is a true magnetic lag, and must not be confounded with the lag in phase resulting in the formation of a loop, or the lag due to self-induction occasioned by eddy currents in the iron.

Slow Changes in the Magnetic Properties of Iron. When iron is continually subjected to rapidly alternating flux-densities, especially when the temperature rises above 100°C., it is found that the hysteric loss is perceptibly increased. This effect has been observed in connection with transformers, where the iron losses play an important part in the working; but in continuous-current dynamos and motors the effect is negligible. (See page 12).

Magnetic Dampers. If a magnetic flux, whether in air or iron, be surrounded by a closed electrical circuit, any change in the value of the flux will induce an e. m. f. in that metallic circuit, tending to oppose the flux change. It has suggested itself, therefore, to builders of dynamos, to surround the magnet-poles with copper bands in order to reduce the possibility of sudden field fluctuation. This feature is employed extensively in alternating-current generators, synchronous motors, and rotary converters, under the name of *dampers* or *damping rings*.

Generation of E. M. F. by Cutting Flux. Whenever lines of magnetic flux are cut by a conductor, an e. m. f. is produced in that conductor, the value of the e. m. f. being one volt when 100,000,000 or 10^8 lines are cut per second. In other words, the e. m. f. depends solely upon the *time rate* of cutting, so that one volt would also be set up if 10^8 lines were cut in one-hundredth of a second. In both cases the time rate of cutting is supposed to be uniform throughout the given time.

The generation of e. m. f. is absolutely certain, no matter when or by what process the lines are cut. A *current*, however, will flow only when there is a closed electrical circuit. A straight bar of copper, for example, cutting across a magnetic field, would have a potential difference established between its ends; but, excepting a slight displacement current at the start, no current would flow until the electrical circuit was completed. We should distinguish, therefore, between the generation of an e. m. f. and the flow of a current. Thus, it may happen that two or more opposing voltages neutralize each other, so that no current whatsoever flows, even though the elec-

trical circuit is complete. This is the case when a copper ring is moved in its own plane across a uniform field; the two halves cut an equal number of lines, and the e. m. f. produced in one half is exactly equal but opposite to that produced in the other half of the ring, making the current-flow zero. This explains the fact that the flux in a coil of wire must be varied in order to permit a current to flow; or, in other

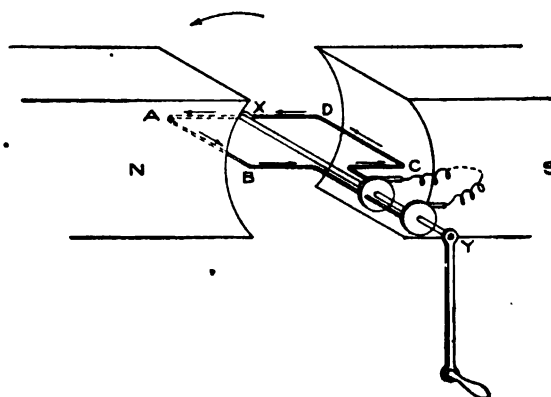


Fig. 19. Illustrating the Elementary Principles of the Generator.

words, the coil must be filled with and emptied of, lines of magnetic induction, in which case an alternating current is produced. This is often stated so broadly, however, that it seems to mean that an e. m. f. cannot be obtained in a uniform field. As al-

ready stated, an e. m. f. *must* be produced whenever magnetic lines are cut, though a flow of current may not result.

Elementary Generator. The simplest form of generator consists of a loop of wire arranged to rotate in a uniform magnetic field, Fig. 19. The generation of e. m. f. in such a dynamo will be as follows: Assume the loop with its plane parallel to the direction of the flux. If, then, the loop be rotated counter-clockwise about its axis XY , the sides AB and CD , which cut lines of magnetic induction, will have an e. m. f. induced in them that will tend to cause a current flow in the directions indicated by the arrows. The value of this e. m. f. will depend upon the speed or *time rate* of cutting; and since this rate is greatest when the plane of the loop is parallel to the direction of the flux, the e. m. f. developed at the instant represented in Fig. 19 will be a maximum. As the loop approaches the 90° or vertical position, the generated e. m. f. gradually decreases because the rate of cutting is diminishing, until, at the 90° position, the cutting of the flux and the generated e. m. f. are both zero. If the rotation is continued, the rate of cutting gradually increases until the 180°

position is reached, where it again becomes a maximum, so that the e. m. f. generated at this instant is also a maximum. The cutting, however, in the two quadrants following the 90° position, has been in the opposite direction to that occurring in the first quadrant, so that the direction of the e. m. f. generated in the second and third quadrant is reversed with respect to that generated in the first quadrant. In passing from the 180° position to the 270° position the rate of cutting and the generated e. m. f. again diminish to zero; and from 270° to the 360° or 0° position, the rate of cutting increases and the direction of the generated e. m. f. is the same as that produced in the first quadrant, the e. m. f. rising once more to a maximum value at the 360° position.

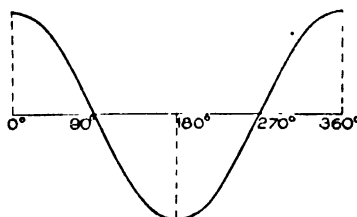


Fig. 20. E. M. F. Curve of Simple Generator Shown in Fig. 19.

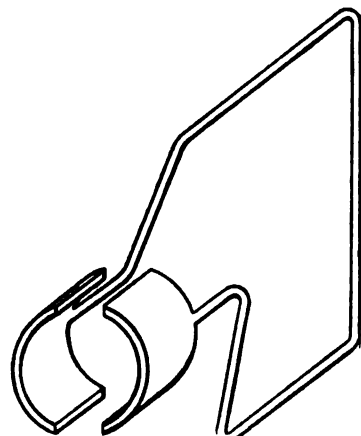


Fig. 21. Simple Commutator Connected to Loop with Single Turn.

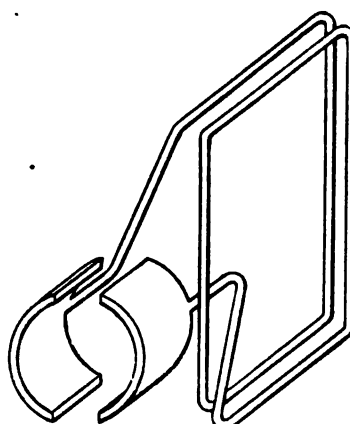


Fig. 22. Simple Commutator Connected to Loop with Double Turn.

is called an *alternating* one, because of its reversal from positive to negative values; that is, it tends to produce a current, first in one direction and then in the other direction, through the circuit. If, however, it is desired to supply the external circuit with a direct or continuous current, a special rectifying device called a *commutator* must be added.

In its simplest form, a commutator consists of a metallic tube slit longitudinally into two equal parts and mounted on a cylinder of insulating material, each half being connected to one terminal of a loop as indicated in Fig. 21. Fig. 22 shows a similar arrange-

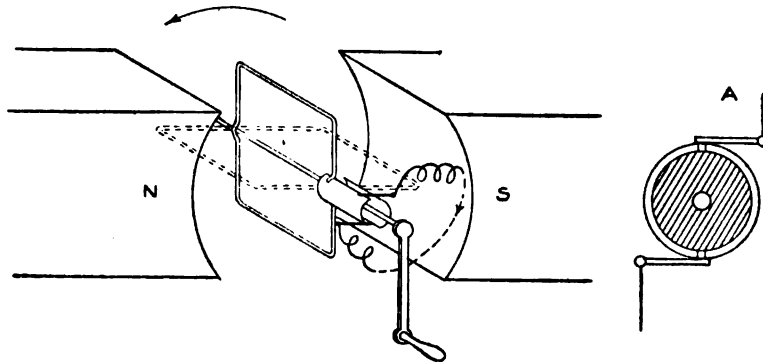


Fig. 23. Simple Form of Generator, Showing Arrangement of Brushes in Contact with Commutator to Give Unidirectional Current in External Circuit.

ment, except that the loop has two turns instead of one. Against this commutator, at diametrically opposite points, press a pair of metallic springs or brushes which lead the current due to the generated e. m. f. to the external circuit. If, as in Fig. 23, these brushes are so set that each half of the split tube moves out of contact with one brush and into contact with the other brush at the instant when the loop is passing through the positions where the time rate of cutting is minimum (as indicated in the enlarged end view of com-

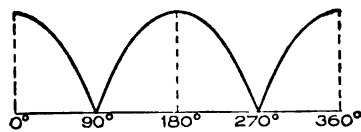


Fig. 24. Curve of Commutated Current.

mutator shown at *A*), the alternating e. m. f. generated will produce in the external circuit a rectified, commutated, or unidirectional current. That is, the current in the external circuit will flow in one

direction. If this external current be plotted, it will be of the pulsating character shown in Fig. 24. This explanation need not be changed, if, for a single loop, we substitute a coil wound on an iron ring as in Fig. 25. The effect of this is to increase the generated e. m. f. by increasing the number of times the electrical circuit cuts the flux. Now, referring again to Fig. 21, suppose, instead of one coil as there shown, we have two coils mounted side by side and

connected in parallel to the commutator segments, we shall then obtain the elementary conditions shown in Fig. 26. If, then—similarly to the arrangement developed in Fig. 25—we place an ex-

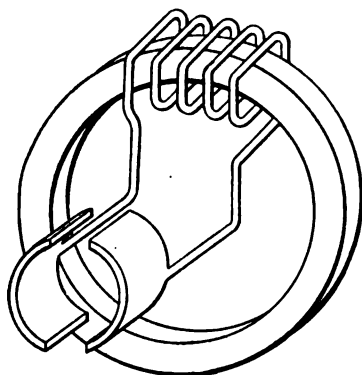


Fig. 25. Simple Ring Armature with One Coil.

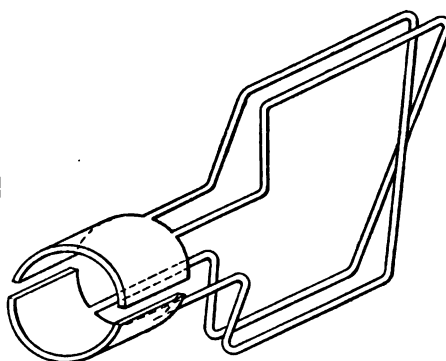


Fig. 26. Simple Loop Armature with Two Coils in Parallel.

actly similar coil at the opposite side of the ring, as in Fig. 27, we see that when its terminals are connected to the same two half-rings as the first, the two coils are in parallel, and though the

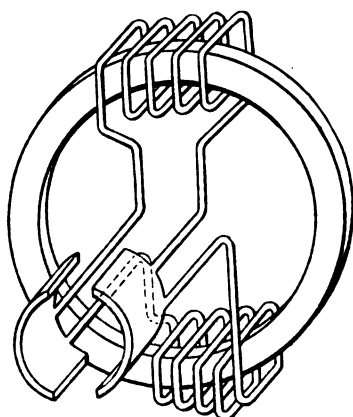


Fig. 27. Simple Ring Armature with Two Coils in Parallel.

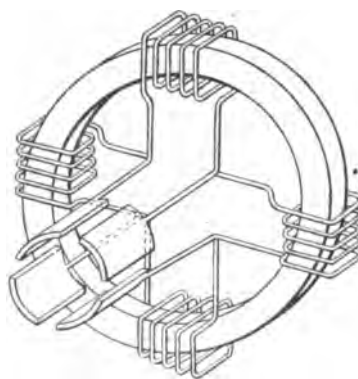


Fig. 28. Four-Part Ring Armature (Closed Coil).

voltage generated by revolving this winding with two coils is no greater than with one coil, the current-carrying capacity of the resultant winding is evidently doubled.

The current obtained, however, from this arrangement has the disadvantage of being pulsating, as already shown. To give continuity to the external current we must multiply the number of gen-

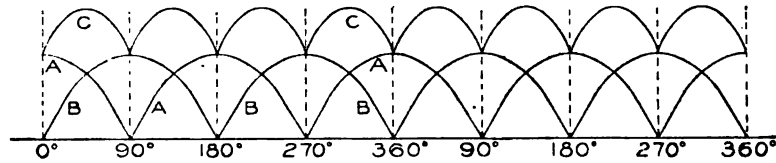


Fig. 28. Curve of E. M. F. and Current Generated by Armature Arrangement of Fig. 28.

erating coils, and also the number of commutator segments, arranging the coils around the armature so that one set will come into action before the other set goes out. If, then, we place upon the iron ring two additional sets of coils at right angles with the first set, as in

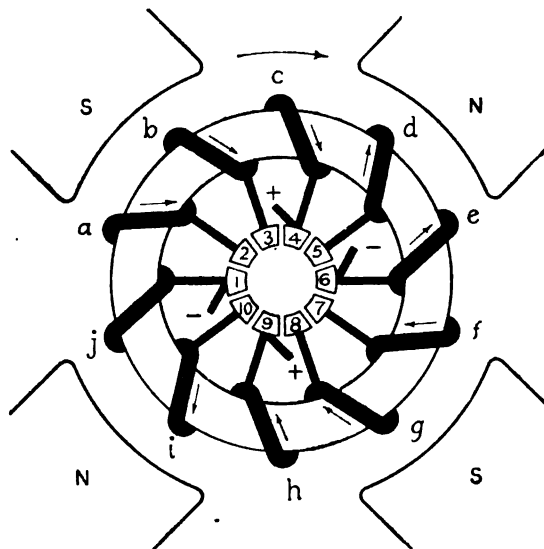


Fig. 30. Diagrammatic Representation of Gramme Ring Winding.

Fig. 28, one set will be in the position of maximum activity when the other is in the position of least action; and Fig. 29 will represent the resulting external e.m.f. and current, which, although continuous (*i.e.*, never becoming zero), is not quite steady, having four slight undulations per revolution. By increasing the number of

coils and commutator segments to a hundred or more, an external current can be obtained in which no undulations can be detected except by the telephone.

On examination of the winding represented in Fig. 28, it is apparent that the four coils are wound in series, the end of the first being connected to the beginning of the second, and so on, the end

of the fourth being finally connected to the beginning of the first—the whole of the winding constituting, therefore, a single, closed coil. Also, it may be noted that the beginning of one coil and the end of preceding one are connected to the same commutator bar. In the practice the commutator is usually made up of a number of parallel

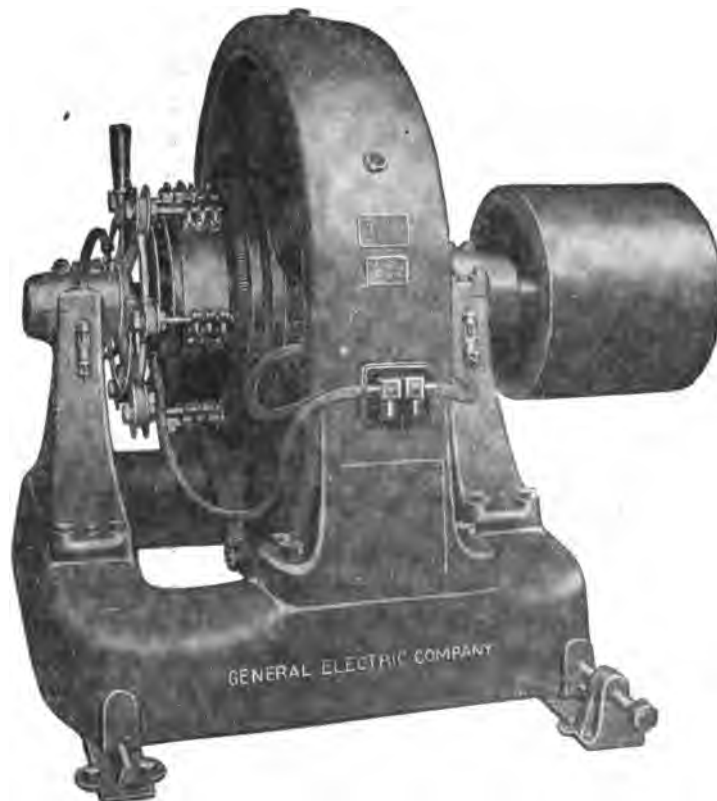


Fig. 31. Typical 6-Pole Belt-Driven Generator. Showing Armature, Field-Magnets, Commutator, and Brushes.

bars of copper set around on, and separated from each other by, insulating material; and the armature is made up of a number of sections as in Fig. 30, which represents a Gramme ring winding. This, and other windings, will be treated more fully later.

Organs of Continuous-Current Dynamos. We have seen that the dynamo in its simplest form consists of two main portions—an *armature*, which in revolving in a magnetic field generates an e. m. f.

in the conductors wound upon it; and a *field-magnet*, whose function it is to provide a flux for the conductors to cut as they revolve. These two parts are always present in all generators, whether for continuous current or for alternating current; and they are easily distinguished (Fig. 31). In almost all continuous-current machines, the field-magnet is a comparatively simple electromagnet which remains stationary; the armature, however, is more complex and usually rotates. In addition, we have seen that continuous-current machines require a commutator, while alternating-current machines are provided with *collecting* or *slip rings*. In either case, brushes are

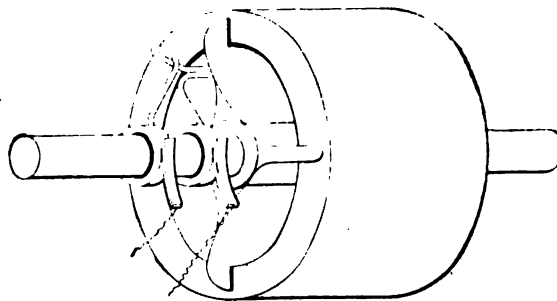


Fig. 32. Armature of Gramme Ring Type.

required to connect the revolving commutator or collector rings to the external circuit.

In continuous-current machines the field-magnet, being usually station-

ary, is combined with the bearings and bed-plate to form the frame of the machine. Similarly, the armature and commutator are supported by a spider and shaft, which rotate in the bearings attached to the frame. The complete machine comprises, in addition, various other mechanical parts taken up in detail later.

Armatures. Any electrical conductor—as, for example, a simple coil of wire—revolving in a magnetic field so as to cut the flux, would act as an armature and tend to have an e. m. f. generated in it. In order to obtain a practically steady direct current, together with maximum effect for a given amount of material, and to secure compactness, convenience of working, and other practical conditions, armatures have resolved themselves into the following types, although, theoretically, any figure of revolution around which coils are placed symmetrically, would answer:

- (1) *Ring armatures*, in which the coils are grouped upon a ring core of iron whose axis of symmetry is also its axis of rotation.
- (2) *Drum armatures*, in which the coils are wound longitudinally over the surface of a drum or cylindrical iron core.

(3) *Pole armatures*, in which the conductors are wound around radial iron cores projecting outward from a central hub.

(4) *Disc armatures*, in which the conductors are arranged in the form of a flat disc the plane of which is perpendicular to the axis of rotation, and usually not comprising an iron core.

The *ring armature* was first employed by Pacinotti in 1860, and described by him in 1865; but it is commonly known by the name of *Gramme*, the French electrician, who reintroduced it in 1870. Gramme wound the coils around the entire surface of the annular core, which he made of varnished iron wire in order to reduce the wasteful effects of eddy-currents; while Pacinotti had the coils wound

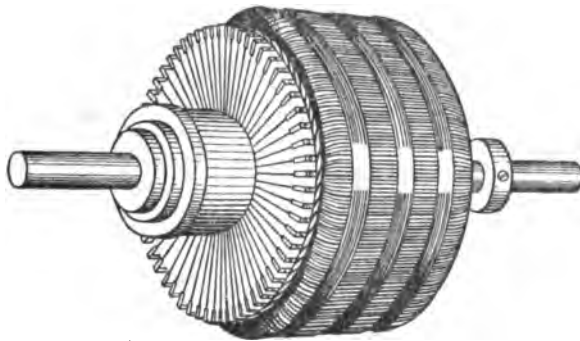


Fig. 88. Ring Armature of Gramme Dynamo.

between projecting teeth upon an iron ring. In ring armatures, the parts of the copper winding which pass through the interior of the ring do not cut any flux, and so are inoperative unless there are pole-pieces of the field-magnet projecting internally, which is not usually the case in practice.* Hence the ring type of winding offers a certain amount of wasteful resistance, which, however, can be made small compared with the resistance of the external circuit. Fig. 32 represents an armature of the Gramme ring type as generally used, although some machines are so designed as to have the outside of the ring act as a commutator, the current being collected directly from the winding by brushes which trail on the periphery of the ring, the inner parts of the conductors cutting the flux. Fig. 33 shows a completely wound Gramme ring armature.

* In case of magnetic leakage through the opening in the ring core, the internal parts of the winding would produce an e. m. f. in the opposite direction to that generated by the outer sections, thus decreasing the effective voltage.

Drum armatures were introduced by Siemens, who wound cores of iron wire upon a frame of non-magnetic material. In their complete form, they were first brought out in 1871 by Von Hefner Alteneck, and improved later by Weston and others. As seen from Fig. 34, this type is even simpler than the ring, and consists in placing the elementary loop before described upon a supporting cylinder of magnetic material, so as to reduce the magnetic reluctance of the gap between the two faces of the field-magnet poles. This type of

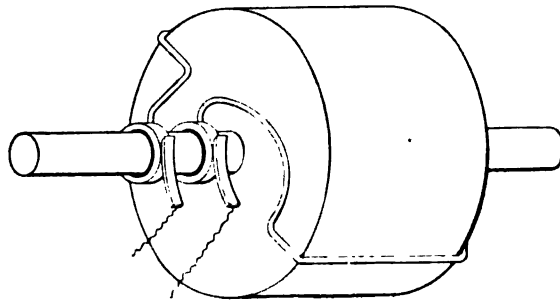


Fig. 34. Illustrating Method of Drum Winding.

armature is almost exclusively used for continuous-current machines of to-day. In Fig. 35 is shown a partly-wound drum armature.

Pole armatures—those having the coils wound upon

projecting poles—were devised by Allan, Lontin, Weston, and others. They were used in Lontin's machines, as shown diagrammatically in Fig. 36. Owing, however, to the great self-induction thus introduced into each section of the winding, and the consequent sparking at the commutator, these machines were not successful. Pole armatures are to some extent used in alternating-current generators.

Disc armatures, illustrated in Fig. 37, have never been very widely used. The interesting feature of this type is the fact that there is no necessity for magnetic conducting material between the two faces of the field-magnet.

Armature Cores. The function of the armature core is two-fold: it supports the generating conductors, and carries the flux from one face of the field-magnet to the other face. On account of its high permeability and its great strength, iron is by far the best material for armature cores. We have seen, however, that when a mass of iron (or other conductor) is rotated in a magnetic field, wasteful eddy currents are set up in the mass. In order to reduce them as much as possible, it has become the practice to build up armature cores of thin soft iron or mild steel discs, insulated from

each other by varnish, rust, or paper. These discs are arranged to have their planes parallel to the direction of the flux and perpendicu-

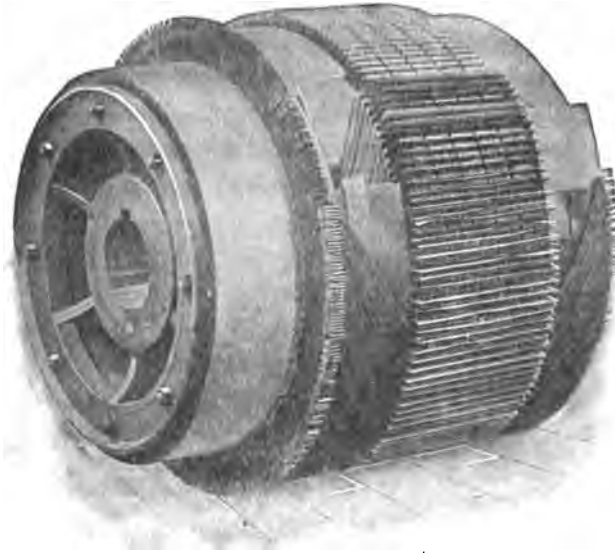


Fig. 35. Partly-Wound Drum Armature.

lar to the flow of eddy-currents. Solid cores of metal should on no account be used in any armature.

Field-Magnet Excitation. In order to generate an e. m. f.

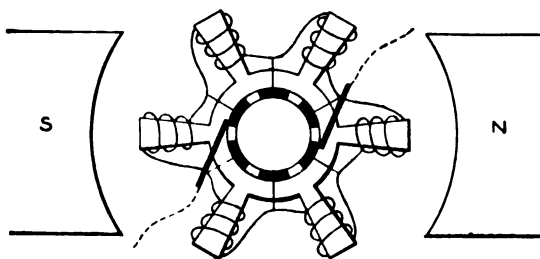


Fig. 36. Armature of the Pole Type.

in the armature conductors, they must cut a flux. This flux is supplied by a magnet, and may be excited therein by five simple methods. These methods may be grouped under two

headings, according to whether the armature of the machine furnishes the magnetizing current or m. m. f. required, or whether it is provided from some other source.

(1) *Magneto-Machine.* In this type of generator, historically the first, the flux was provided by a permanent magnet as shown diagrammatically in Fig. 38. This method has the disadvantage of requiring a much bulkier machine in comparison with the methods to be described later, since permanent magnetism cannot be maintained at the high flux-density which may be produced by an exciting coil. It has, however, the advantages of simplicity and constancy, but is used only in the smallest of generators employed for example,

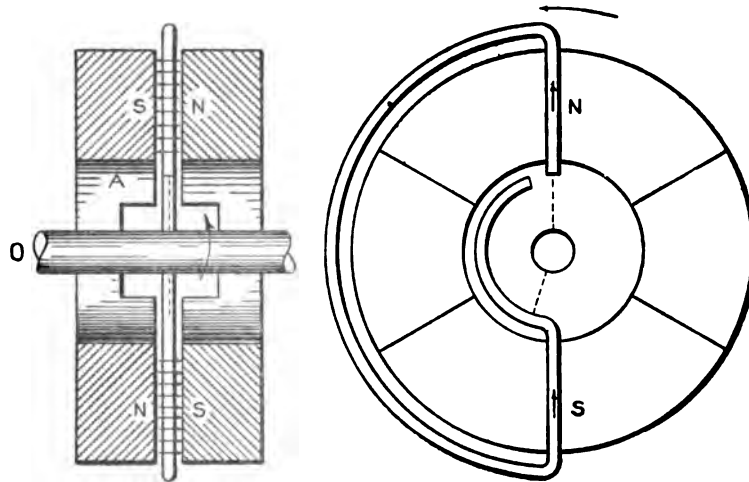


Fig. 37. Armature of Disc Type with Two Inductors in Series.

to furnish current for ringing bells, for ignition in internal-combustion engines, etc.

(2) *Separately-Excited Generator.* The next step was to excite the field-magnets by means of a coil fed from some source of electrical energy other than the generator itself. This method, outlined in Fig. 39, produces the same results as the magneto method, without the disadvantage of great bulk. It requires, however, a separate machine or battery for excitation purposes solely, and the method is not employed in continuous-current practice, except where many machines are in operation, or where their terminal voltage exceeds 800 volts. It is largely employed in exciting the fields of alternating-current generators, since an alternating current will not produce a unidirectional magnetic field.

In either of the methods just mentioned, the e. m. f. of the machine may be governed in three ways—namely, by (a) altering the speed of rotation of the armature; (b) by varying the number of effective conductors by moving the brushes; and (c) by changing the magnetic flux through the armature. The latter is altered in the case of magneto-machines by shunting the flux away from the armature through an auxiliary piece of iron. In the case of separately

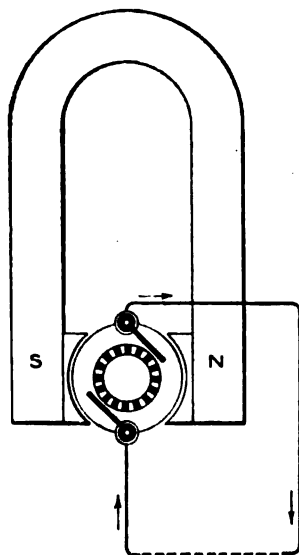


Fig. 38. Diagrammatic Representation of Magneto-Generator.

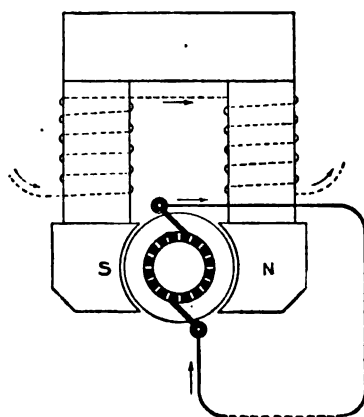


Fig. 39. Diagrammatic Representation of Separately-Excited Generator.

excited machines, the flux is varied by regulating the exciting current or the number of turns of the solenoid.

Generators of the continuous-current type may be made *self-exciting* by either of four methods. The whole current supplied by the machine to the external circuit may be passed through the solenoid, or a part of the total current may be passed through the field-winding; or two field-windings may be employed, one traversed by the load current and the other by the shunt current; or, finally, the field-exciting current may be produced by an e. m. f. generated by a separate winding on the armature of the generator.

(3) *Series Dynamo*. The series continuous-current generator outlined in Fig. 40 has but one circuit. It has, however, the disadvantage of not starting to generate until a certain speed has been reached or unless the resistance in the external circuit is below a certain

limit. It also is liable to become reversed in polarity, thus unfitting it for electrolytic work. Any increase in its external resistance, at a given speed, diminishes the current stream that excites the magnetic circuit, thereby lowering the e. m. f. Conversely, reduction of external resistance tends to increase the e. m. f. of the machine until the IR drop and the armature reaction become so large that the available voltage falls more rapidly than the field stream increases. The only series generators actually employed supply *arc lamps in series*, and are provided with automatic regulators to maintain

constant current; hence the external voltage and power are directly proportional to the external resistance.

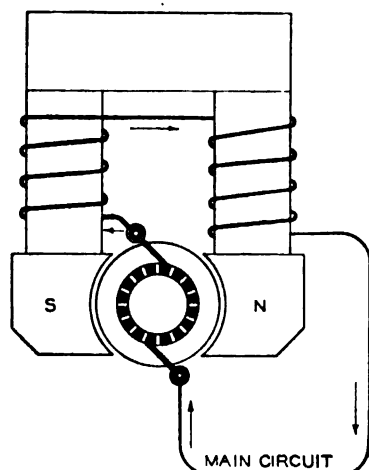


Fig. 40. Diagrammatic Representation of Series Continuous-Current Generator.

such as to reduce its generated e. m. f. to zero. Its polarity never reverses of itself; and although it is a trifle more expensive to buy than the corresponding series machine, its self-regulating properties more than overbalance this. The amount of energy required for excitation in either series or shunt field-windings for identical machines, is precisely the same, since to produce a given flux (as shown in the discussion of the magnetic circuit) demands a definite number of *ampere-turns*. In the series machine, the *turns* of wire are few in number, while the current in *amperes* is relatively large. In the shunt type, the reverse is the case.

(5) *Separate-Circuit, Self-Exciting Generator.* The third type of self-exciting machine is that in which the field circuit is supplied by only part of the armature, or by separate windings on the armature,

(4) *Shunt Dynamo.* In the shunt-wound generator, Fig. 41, only a small part of the current in the armature passes through the field winding. The field-exciting circuit F_{sh} has, therefore, a relatively high resistance compared with that of the external circuit. This machine is tolerably self-regulating within certain limits, when properly designed; but if overloaded, its internal actions are

as represented in Fig. 42. This arrangement is adopted for A. C. generators and for D. C. machines in which the e. m. f. generated is over 800 volts, since it is undesirable to apply such voltage to field excitation. In effect, however, it is almost the same as the separately excited machine (No. 2, above).

Generator Regulation. In all the simple methods of field excitation just described, the e. m. f. generated by the dynamo varied more or less with load. If the load were constant (*i.e.*, if the same number of lamps were being supplied all the time), the generator could be designed to give a predetermined terminal voltage. But under usual working conditions, the load connected to an electric generator—such as lamps, motors, or other devices—is continually changing, so that it is essential to provide some device whereby its e. m. f. may be varied to suit the varying load. The generated e. m. f. is the sum of the terminal voltage and that lost in overcoming internal reactions, the latter quantity varying with load.

As stated previously, there are three methods for regulating the generated e. m. f. of the dynamo—namely, by varying the speed of rotation of the armature, by varying the magnetic flux, and by changing the number of effective or active armature conductors.* Of these three possible methods, however, the only one utilized is that of varying the magnetic flux, it having been found more convenient to regulate the prime mover for constant speed than for speed increasing with load, while the method of changing the effective armature conductors by shifting the brushes is conducive to bad sparking at the commutator. As has been noted, the most advantageous way to vary the magnetic flux is to vary the current in the energizing coils.

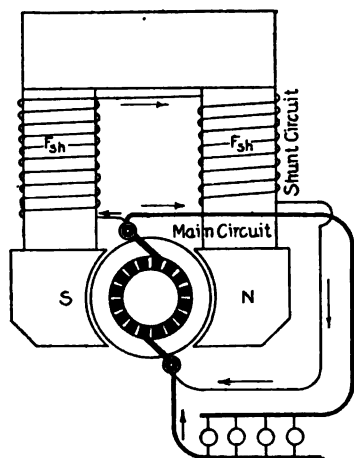


Fig. 41. Diagrammatic Representation of Shunt-Wound Generator.

*The expression "active armature conductors" refers to those conductors which are actually cutting flux and generating an e. m. f. at any instant.

Since the current in the field-exciting coils is dependent upon the e. m. f. impressed at their terminals and upon their ohmic resistance, we can increase the magnetic flux by decreasing the resistance of the field-exciting circuit or by increasing the terminal voltage im-

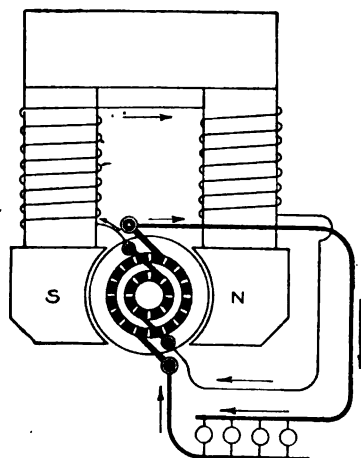


Fig. 42. Diagrammatic Representation of a Separate-Circuit, Self-Exciting Generator.

pressed there. Also, the flux may be made to increase with load, by passing the external current of the generator through a few turns of thick wire, called *series turns* or *compounding turns*, placed upon the field-cores. The first method is usually non-automatic, and is applicable to shunt and separately excited machines; the second is applicable to separately excited machines; and the third, to both types; and a generator thus equipped is called a *compound generator*.

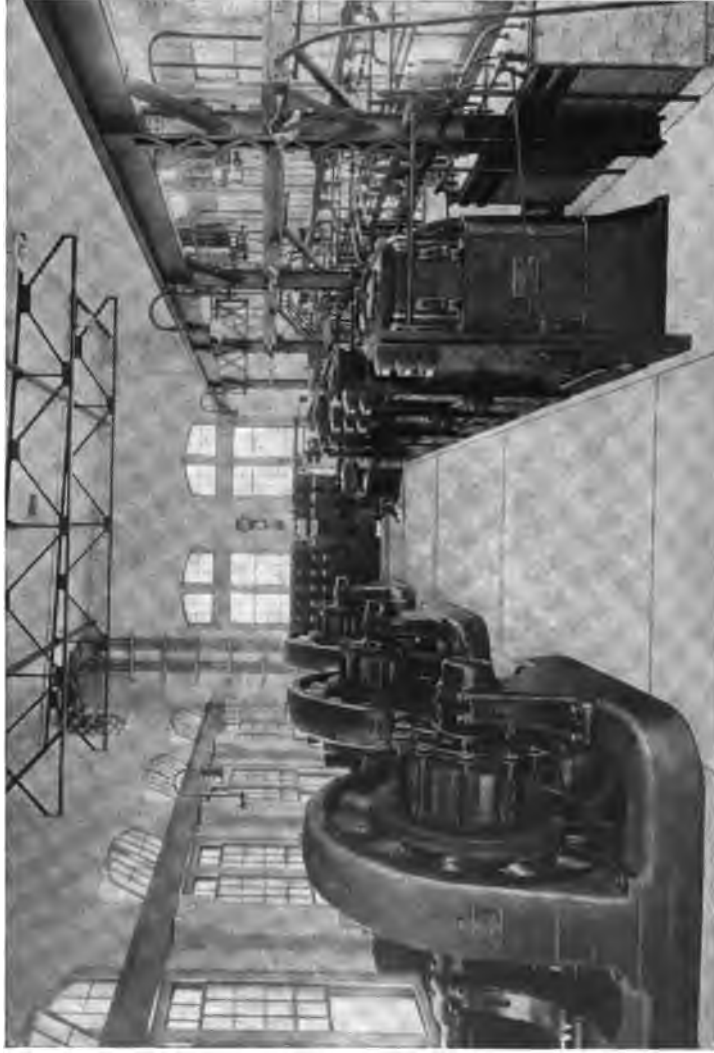
Methods of Compounding. (1)

Separate and Series (Deprez).

The connections are shown diagrammatically in Fig. 43, a separate source of e. m. f. being used to produce the initial and constant excitation, while the external current of the machine is led through a series winding, thus compensating for the internal drop of the generator to any desired degree, even *increasing* the terminal voltage with load if desired.

(2) *Shunt and Series.* By far the most widely used of all compounding schemes, however, is the one in which series turns are added to the plain shunt winding, as illustrated diagrammatically in Fig. 44. By properly proportioning the ampere-turns in the shunt and series coils, the terminal voltage-load curve may be made to take any desired form. For instance, it may be made constant, increasing or decreasing throughout the rated load range of the machine. This arrangement will be considered in detail later on.

(3) *Booster Method.* This consists essentially of an auxiliary generator in series with the main machine, the e. m. f. of the former being low; and since its field winding is in series with the external circuit, it will automatically regulate the voltage of the combination in accordance with the load



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(4) *Miscellaneous Methods.* If the generator armature be wound according to a special scheme devised by Sayers,* the field excitation may be produced by a simple shunt winding, and a compounding effect produced by giving the brushes a backward lead. Other methods of compounding may be found in S. P. Thompson's "Dynamo-Electric Machinery."

Actions in the Armature. Thus far we have considered the armature and the field of the generator separately, assuming that the former did not affect the latter. It is found, however, that when the armature of a generator or motor is carrying current, its action is not the same as when it carries no current, owing to the distortion of the field flux by the magnetization of the armature. In order

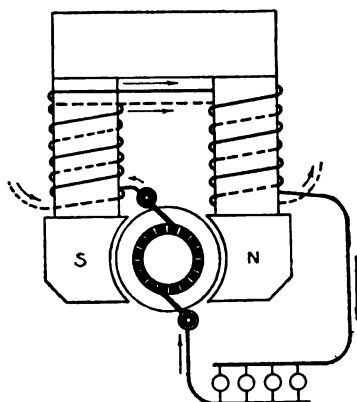


Fig. 43. Separate and Series Method of Compounding.

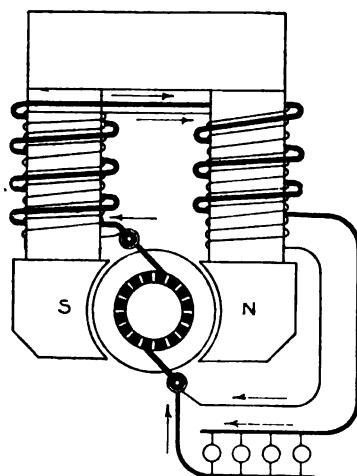


Fig. 44. Shunt and Series Method of Compounding.

to study the effects produced, we shall consider a dynamo of the simple bipolar type (Fig. 45) with a ring armature, when the machine is operating without and under load.

Suppose the armature to be rotating clockwise, when viewed from the commutator end, and that the north pole of the field-magnet is at the right of the armature, the south pole being on the left, as in Fig. 46. The flux will then pass from right to left through the armature; and the e. m. f. generated in the moving conductors of the armature is, in accordance with Maxwell's law, as follows:

* See E. Arnold's *Gleichstrommaschinen* (Erster Band, Berlin, 1903), pages 417, 449, et seq.

In all the conductors which are ascending, the generated e. m. f. is directed toward the observer; while in all the descending conductors, the generated e. m. f. is directed away from the observer. If the circuit through the armature is closed, the generated e. m. f. will produce a current flowing in the same direction; and in Fig. 46 the current-flow in the armature is toward the top and away from the bottom on both sides. This result is obtained when the armature is wound right-handedly, being the opposite if the winding is left-handed. With a drum-wound armature, the result is the same; but the diagram is more complex on account of the end connections.

It will be noted that the path of the current is from brush to brush, through each of the armature coils, without going to the

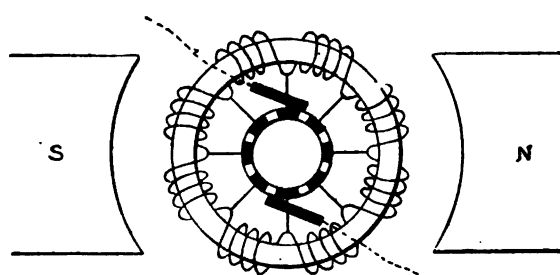


Fig. 45. Diagrammatic Representation of Simple Ring Armature.

commutator except where it passes out to or returns from the external circuit. We have seen, however, in the ideal dynamo, that the e. m. f. generated in an

armature coil is proportional to the time rate at which the flux is cut. In the case illustrated in Fig. 47, no two armature coils are cutting the same amount of flux at any given instant, so that the voltage generated in each coil depends upon its position in the field. Since one-half of the coils are connected in series between the brushes, the total difference of potential (p. d.) measured at the latter will at any instant be the sum of the instantaneous e. m. f.'s generated in the individual coils.

If the field were uniform, it is plain that the flux cut at a given instant by any one coil would be proportional to the sine of the angle which it makes with the direction of the field at that instant; so that if we plot the values of these instantaneous potentials as ordinates, and the corresponding angles as abscissæ, we obtain Fig. 47.

Thus it is seen that the p. d. obtained at the brushes may be compared to that obtained at the terminals of a battery connected as shown in Fig. 48, each cell representing an armature coil and being

supposed to supply an e. m. f. equal to that generated by the coil it replaces. The terminal voltage will then be obtained by adding all these potentials between the 0° and the 180° positions in Fig. 47, or integrating the voltage curve between these limits, the negative part being exactly equal to the positive half if the dynamo is symmetrical. The sum thus obtained grows slowly at first, then rapidly, and slowly again as it reaches its highest value, repeating this program in the other half-circumference. These facts are shown at reduced scale in Fig. 49. In the actual dynamo, this integration is effected because the coils are connected in series; and it is possible to demonstrate this experimentally.

Exploration of Potentials around a Commutator. Several more or less simple ways of showing the distribution of the generated e. m. f. around the commutator of a dynamo, have been suggested,* but only one, Mordey's method, will be taken up here. It consists in connecting one terminal of a voltmeter, preferably an electrostatic one, to one brush of the machine, and the other terminal to a small pilot brush *b* (Fig. 50), which can be moved from point to point around the commutator. The armature of the generator is then rotated at its rated r. p. m. (revolutions per minute); and, starting at the brush *N*, *b* is placed in successive positions around the commutator, the voltmeter reading in each position being noted, together with the corresponding angular situation of *b*.

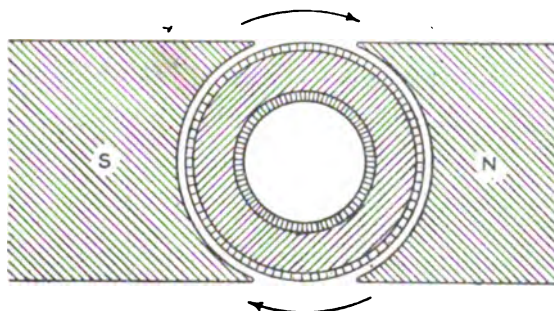


Fig. 46. End View of Ring Armature in Bipolar Field.

These results, plotted with the voltage readings as ordinates and the corresponding values of angular situations of *b* as abscissæ, are as represented in Fig. 51, when the armature is carrying no current. The curve so obtained is not usually a true sine curve in commercial machines, because the magnetic field in which the armature rotates is not uniform. Also, we shall see later that when the armature

*See S. P. Thompson's "Dynamo-Electric Machinery," Vol. I. (N. Y., 1904), page 204.

carries a current, its presence causes a further distortion in the distribution of the flux. Furthermore, the setting of the brushes

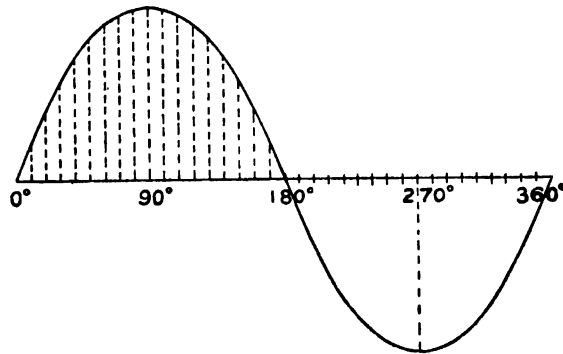


Fig. 47. Curve of Induced E. M. F.

or an injudicious shaping of the pole-pieces will cause irregularities to be present in this curve, examples of which have been given by Von Gaisberg*, Kohlrausch**, M. E. Thomson***, Ryan†, and Shephardson††.

Reactions in the Armature. This leads us to consider the reac-

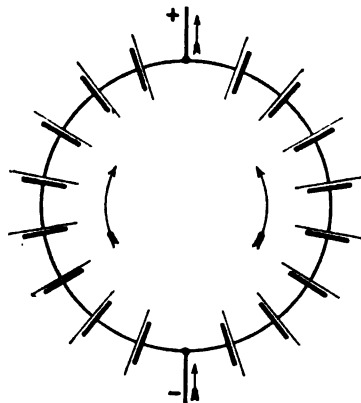


Fig. 48. Battery Analogy of Simple Dynamo.

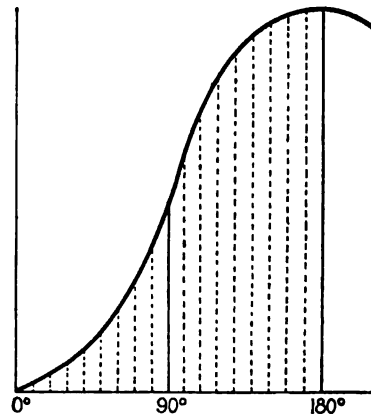


Fig. 49. Integrated Curve of Potentials.

tions of the armature when the generator is operating, which are manifested in many ways, the most important being:

- (1) A tendency to *cross-magnetize* the armature.
- (2) A proneness to spark at the brushes.

* *Elektrotechnische Zeitschrift*, vii 67, Feb. 1886.

** *Centralblatt für Elektrotechnik*, ix 419, 1887.

*** "Electrical World," xvii 392, 1891.

† Trans. Amer. Inst. Elec. Engrs., vii 3, 1890.

†† "American Electrician," x 453, 1898.

- (3) Variation of the neutral point of the armature with the amount of current.
- (4) The consequent necessity of shifting the brushes.
- (5) A resultant tendency to demagnetize the armature.
- (6) Losses due to eddy currents in the pole-pieces, armature core, and coils.
- (7) A resulting difference between the input and output.

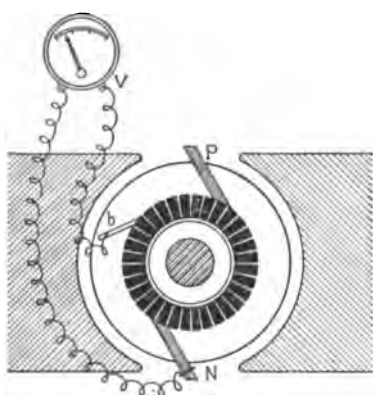


Fig. 50. Mordey's Method of Exploring Potentials around Commutator.

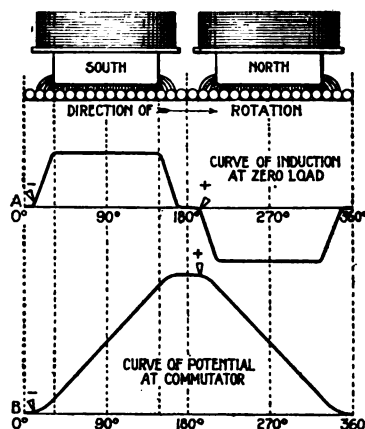


Fig. 51. Undistorted Field.

As these reactions have much effect upon the operation of the commercial machine, they will be considered in detail.

Cross-Magnetizing Effect of Armature Current. We have seen from Fig. 48 and the accompanying text, that the armature of a generator may be likened to a combination of voltaic cells; but the armature carrying current manifests a magnetic effect absent in the latter.

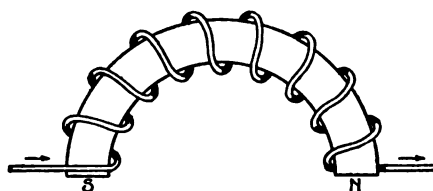


Fig. 52. Poles on Half-Ring.

If we consider the solenoid of page 4 to be bent around so as to form a semicircular ring, and to have inserted into it an iron core of the same form, one end of this core would act as a north pole, and the other end as a south pole, when current circulates in the winding (Fig. 52). By taking an exactly similar semicircular ring and placing the two together so that their north poles and the south poles are respectively coincident, we are able to repro-

duce the magnetic effect of current flowing in the armature. That is, when the generator supplies energy to the external circuit, the armature has poles produced in it corresponding to the brushes—

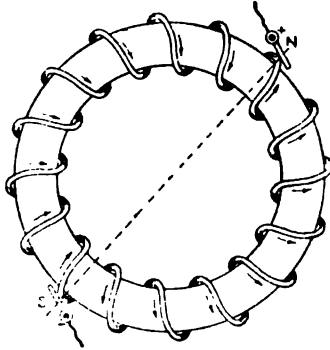


Fig. 53. Circulation of Current around Ring Armature.

namely, where the current enters and leaves the winding. This magnetization of a simple Gramme ring armature (Fig. 53) is indicated in Fig. 54, the general direction of the flux being through the armature core along both paths from *a* and *b* to *n* and *s*, where it emerges into air, forming respectively the poles of the armature. The main portion of this flux returns outside the ring, while a small portion passes across the interior. This latter

portion is extremely small in commercial machines, on account of the presence of large masses of iron in the pole-pieces which are outside.

The cross-magnetization of the armature produces a distortion of the flux in it; but this would have small effect upon the e. m. f. if the line of commutation did not also change with the armature current. This change necessitates the moving of the brushes; and then the armature not only produces a cross-magnetizing effect, but also has a demagnetizing tendency. It is this latter which diminishes the generated e. m. f.

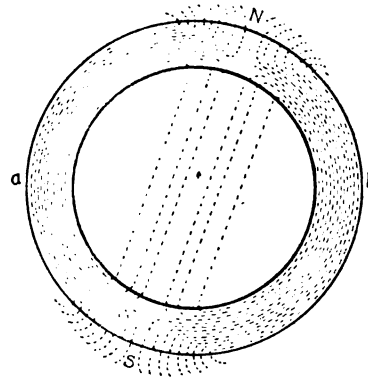


Fig. 54. Magnetization Due to Armature Current.

In order to study the result, let us suppose the simple bipolar dynamo of Fig. 45 to be arranged so that current may be passed through its field windings, its armature when rotating, or through both. When the field alone is excited, the flux distribution will be substantially as indicated in Fig. 55—that is, quite uniform in the

pole-pieces, air-gaps, and armature. If, now, the field-exciting circuit be opened, and if a current be supplied to the rotating armature equal to its rated load current, the flux distribution shown in Fig. 56 will exist. By combining these two conditions of the flux, there is produced the distortion shown in Fig. 57, which is the resultant flux distribution in the generating portion of the machine. The magnetism is distorted in the direction of rotation, as if the armature tended to draw after it the flux issuing from the field-poles. But this is not the physical fact, because we find that in electric motors the flux is distorted in a direction *opposite* to that of the rotation of the armature. In fact, the flux-distribution is the same whether the armature turns one way or the other, or not at all. On account of this flux distortion, brushes must be set, not midway between the field-poles, but, in the case of generators, somewhat ahead of this line of symmetry. Consequently the armature m. m. f. will be oblique to that due to the field-magnet, and a further distortion will result.

These relations are shown vectorially in Fig. 58, the line OF representing in direction and magnitude the flux due to the field-magnet, and the line OA' the direction and magnitude of the flux set up by the armature current with the brushes in the line of symmetry or vertical position. In this case, OR' represents the resultant flux in value and direction, and the brushes should be shifted to the line OA'' , perpendicular to OR' . The armature component of the

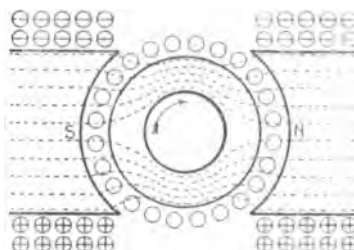


Fig. 55. Flux Due to Field Alone.

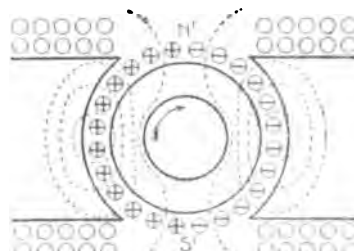


Fig. 56. Flux Due to Armature Alone.

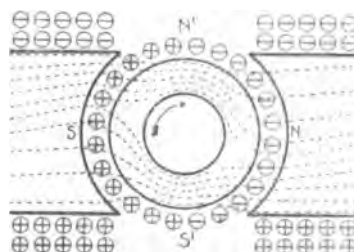


Fig. 57. Flux Due to Field and Armature.

flux also shifts to this direction, but with unchanged magnitude because the ampere-turns and other relations of the magnetic circuit are not varied. This will produce a new resultant OR'' , and the

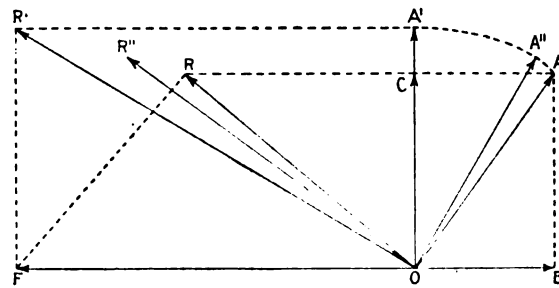


Fig. 58. Magnetic Reactions in Armature.

brushes should be shifted until the line of commutation OA is approximately perpendicular to OR , the final flux vector. These conditions are also represented in Fig. 59,

OF being the field-magnet flux, OA the armature flux with the brushes shifted, and OR the resultant with the main line of the flux (PQ) as an extension of it.

In the case of drum-wound armatures, the phenomenon is similar but not so easily traced. In consequence of the overlapping of the end-connections, the magnetizing effects of some of the coils are neutralized, and as a result the production of poles is not so marked. Neither

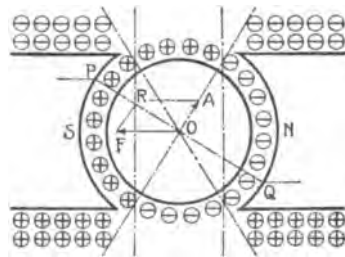


Fig. 59. Back and Cross Ampere-Turns.

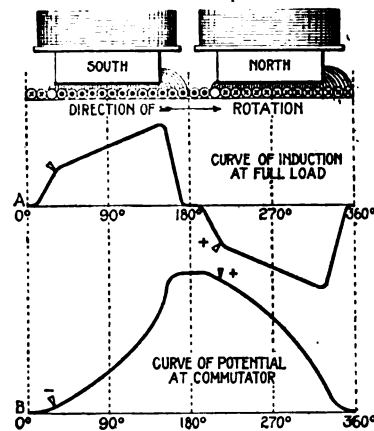


Fig. 60. Curve of Armature Distortion.

can there be any internal field. As a matter of fact, drum-wound armatures are not troubled to the same extent with induction effects as are ring-wound ones. With these exceptions, however, the facts here considered apply equally to drum-wound and ring-wound armatures.

The distortion of the flux through the armature also produces a distortion in the wave of induction, as may be shown by exploring the potential differences around a commutator by Mordey's method, when the machine is carrying its rated load. Such a curve is shown in Fig. 60.

Sparking at the Commutator. On page 20 we have seen that the rotation of the armature in the field of the machine generates alternating currents in the conductors. A consideration of Fig. 57 shows that all the current flows toward the spectator in the conductors which are rising, and away from the observer in all the descending conductors, the brushes in this case being supposed present at N' and S' . Thus, when a coil passes under one of the brushes, the direction of the current in that coil is *reversed*. Owing to the fact that even a single armature coil possesses some self-induction, the current cannot change instantaneously; that is, a certain definite interval of time is required, dependent upon the self-inductive property of the armature coil, as well as upon its resistance. During this interval, and until the whole current can take the new path through the coil, a portion of the current continues to flow from the receding commutator bar, through the air, to the brush, in the form of a spark. It is the interruption of this latter current, as the commutator bar leaves the brush, that produces the spark.

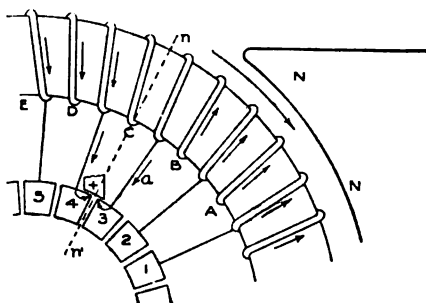


Fig. 61. Illustrating Requirements for Non-Sparking Condition of Commutation.

Commutation. In order to understand exactly what happens when a current is commutated, let us consider what takes place in one section of an armature winding, and at the two commutator bars attached to the latter, when the bars pass under a brush.

Fig. 61 shows a portion of a ring-wound armature with its coils A , B , C , D , and E connected to segments 1, 2, 3, 4, and 5 of the commutator, and a positive brush just beyond the leading tip of one of the pole-pieces. The line nn' represents a line drawn in space so as to cut the commutator at a point where the voltage between the

brush and the bars thus passed through is zero. The brush is assumed placed in this line.

Now, before any given section of the winding reaches the brush shown in the figure, a current will be flowing in it in the direction of the positive brush; and after the section has passed the brush, the current, although reversed in direction, is still flowing towards the brush.

The figure shows the instant at which coil *C* is short-circuited by the brush through the commutator bars 3 and 4; and it is during the brief interval of this short circuit that the current in coil *C* must be reduced to zero, reversed, and then built up again in order that there shall be no tendency for a spark to form between the brush and the bar 3 at the instant they part.

As to the establishment of a reversed current in section *C* while it is short-circuited by the brush, it must be remembered that this coil is at this instant supposed to be occupying a position such that there is no e. m. f. being generated in it; that is, it is in a neutral position. In coils to the immediate left and right of coil *C*, however, e. m. f.'s are being generated in such a direction as to cause the resulting current to flow *towards* the brush. If, therefore, we move the brush forward—that is, in the direction of rotation—from its present position in the neutral line, the section short-circuited by that brush will be placed in a region where a p. d. will be generated between its terminals in such a direction as to assist the reversed current above mentioned. Also, the greater the forward lead—that is, the further away from the neutral line in the direction of rotation the brush is moved—the greater will be the p. d. so generated; so that by trial, a position of the brush may be found where the condition of sparkless collection is fulfilled.

The use of high-resistance carbon brushes tends to cause a decrease to zero of the current existing in the sections before they reach the brush, since the latter forms part of the short circuit. Their use also aids the establishment of the reversed current in the short-circuited section, before the brush and segment part company. This is due mainly to the contact resistance between the brush and the commutator, as follows:

The current flowing across the contact area of the brush and leading segment under it (in the figure, segment 3), produces a drop

of potential there, which is small on account of the large area of contact, at the instant depicted. A moment later the brush is making better contact with segment 4, and poorer contact with segment 3, so that the voltage drop across the contact area of the brush and 3 has risen above that of the brush and 4. Hence a current will tend to flow from segment 3 to segment 4, as a reverse current through C , being produced by the difference of potential between them. This state is comparable to that of the ordinary potentiometer, where a "drop" acts as an e. m. f. in producing a current flow. The voltage resulting from this potential difference across the two contact areas mentioned, assists that tending to produce reversal.

Thus, as the commutator moves under the brush (assuming the latter to have a forward lead), the e. m. f. for reversal, the p. d. due to the varying contact area of the brush, and the resistance of the short-circuited coil, combine to reduce the current in the latter to zero, while the self-induction of the coil tends to prevent any change of the current in it.* This zero condition should occur when the

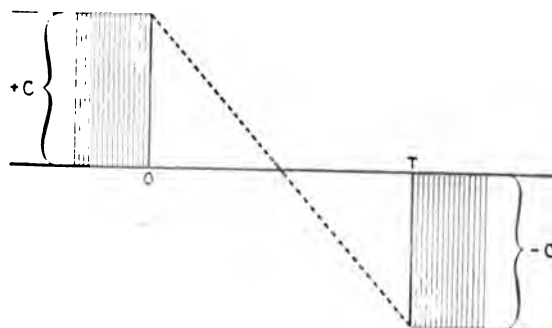


Fig. 62. Curve of Commutation—Ideal Case.

areas of contact between the brush and the two (in this case) bars passing under it are equal. Then, when the segments leave this position, the p. d. between them will increase, thus assisting the direct e. m. f. (produced in the coil by the flux from the hindward pole-horn) in establishing a current in the coil in the reverse direction. Opposing this are the resistance and self-induction of the coil. With proper conditions, the various reactions mentioned may be so proportioned as to produce in the coil from which the short circuit is about to be removed, a current equal in amplitude and direction to that flowing towards it from the preceding coil. In the figure, coil

*See S. P. Thompson's "Elementary Lessons in Electricity and Magnetism," N. Y., 1903, pp. 466 *et seq.*

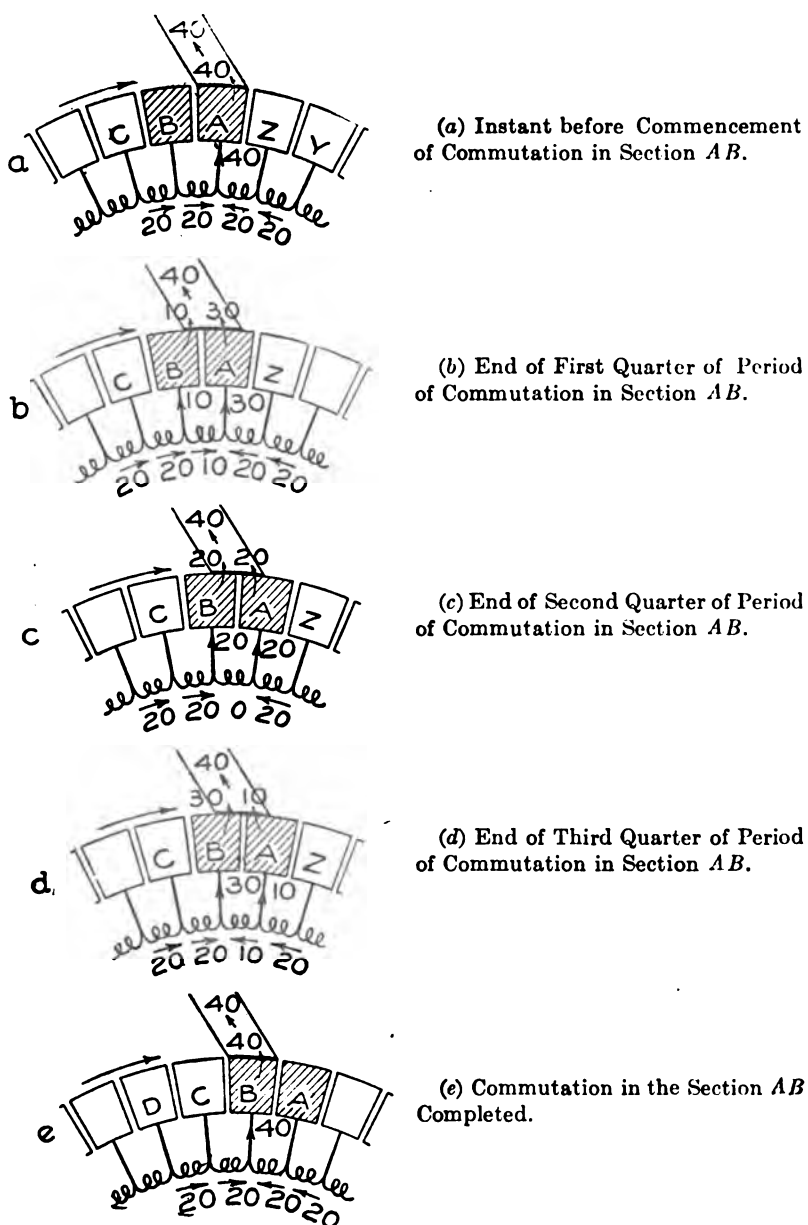


Fig. 63. Process of Commutation.

C would be the one to have the short circuit removed; and B , the preceding coil. Then segment 3 will pass out of contact with the brush without a spark attempting to follow.

Resistance during Reversal. Let us assume that during commutation the brush contact resistance is inversely proportional to the area of contact. Then, in the ideal case, where the coils of the armature are devoid of resistance and inductance, the curve of commutation will be as shown in Fig. 62, C representing the value of the current to be commutated, O the instant when commutation commences, and T the period requisite for this action. Here the current gradually diminishes to zero at the middle of the commutation period, and reaches its negative maximum value at the end of the time T . This process is shown in detail in Fig. 63, the brush being wide enough to span one commutator bar.

In this case 20 amperes flow from either side of the armature to the brush, the latter leading away 40 amperes. If we suppose the brush area to be one square inch, then, when the commutator is in the position indicated by Fig. 63 (*b*), the area of contact of the segment A is reduced to $\frac{3}{4}$ square inch, while that of the segment B has become $\frac{1}{4}$ square inch, so that 10 amperes will flow into the brush from B and 30 amperes from A , the additional 10 amperes through the latter coming from the short-circuited coil. When the commutator has moved forward so that the area of contact of each brush is the same—that is, $\frac{1}{2}$ of a square inch— A and B will each pass 20 amperes to the brush from either side of the armature, the coil undergoing commutation carrying no current at this instant (see Fig. 63, *c*). At the end of the third quarter of the commutation period, the commutator has reached the position shown in Fig. 63 (*d*), the area of contact of segment A with the brush being $\frac{1}{4}$ of a square inch, while that of B is $\frac{3}{4}$ of a square inch. Hence A will contribute 10 amperes and B 30 amperes to the brush, the coil undergoing commutation now carrying a current in the direction reverse to that indicated in Fig. 63 (*b*), and in the same direction as the current in the coils on the right. At the end of the commutation period, the current in coil A – B has increased to the full value of that flowing in its right-hand neighbor; and when the brush and segment A part company no spark will result.

Fig. 62 shows the variation of the current during this period,

if we neglect the resistance and inductance of the armature coils. It therefore remains to consider the effect of these reactions.

Commutation Curves. If the resistance of the armature coils be not negligible in comparison with the contact resistances, then the current collected will not be rigidly proportional to the areas of contact. For, suppose that in Fig. 63 (*b*) the contact resistance over *A* is 0.04 ohm, and that that over *B* is 0.12 ohm; then, if the resistance

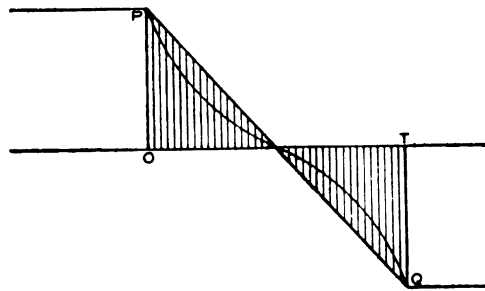


Fig. 64. Curve of Commutation,

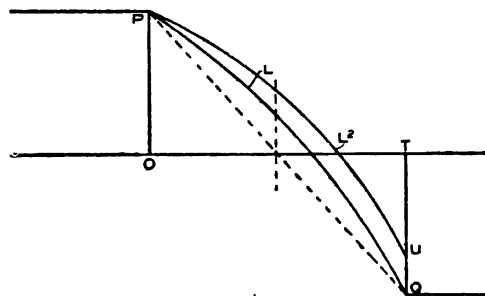


Fig. 65. Curve of Commutation, with Self-Induction.

of one coil of the armature be taken at the exaggerated value of 0.01 ohm, 29.6 amperes will go through *A*, and 10.4 amperes will pass through *B*. In other words, the presence of resistance in the coils of the armature reduces the ratio of currents during the first half of the commutation period, and increases this ratio during the second half. This is shown graphically by the curved line in Fig. 64, the straight line indicating the ideal case.

The effect of self-induction, although not easily shown quantitatively, would modify the ideal current curve as indicated by $PL'Q$ in Fig. 65, $PL'U$ showing the result obtained with increased self-induction. Self-induction tends to retard any change in the current, so that the same is not completely reversed at the end of the commutation period. At the last instant, then, as the surface of contact between the segment *A* and the brush diminishes to zero, the contact resistance rises with extreme rapidity. The product of this resistance and the still uncommutated part of the current, will constitute a p. d. between the retreating segment *A* and the tip of the brush. This p. d., represented graphically by QU in Fig. 65, tends to set up a spark, and may be briefly called the *spark* or *maintaining e. m. f.*

The resulting commutation curve for any machine is made up of these two effects, the quantity of each depending upon the design, and of some details at present obscure. Messrs. Everett and Peake* found experimentally that the curve had the form shown in Fig. 66. Curve *A* indicates the initial rise which may obtain at light loads, with an oval resultant at the negative end. *B* illustrates under-commutation with insufficient lead. *C* shows, with increased load, a rapid reversal at the beginning of the commutation period, but under-commutation toward the end. *D* represents a gradual fall of the current, which slackens toward the end.

Effect of Increasing Breadth of Brush. Increasing the breadth of the brush not only lengthens the period of commutation, but also permits commutation to start in one coil before the preceding coil has entirely passed through this stage.

In Fig. 67, let us assume the brush to have an area of 3 square inches, and that it can completely cover two segments at one time, the current collected by the brush being 120 amperes. Then Fig.

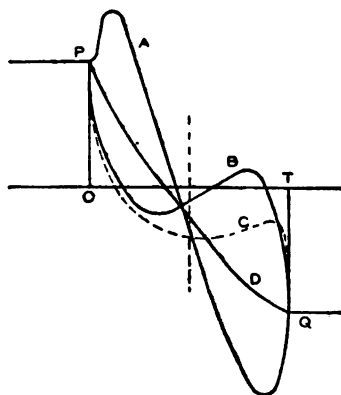


Fig. 66. Curve of Commutation Observed by Everett and Peake.

67 (*a*) shows the state of affairs when the segments *A* and *Z* are under the brush. An instant later, the commutator, in moving clockwise, starts to uncover segment *Z* and to cover segment *B*, so that at the end of the first quarter of the period of commutation, the result will be as indicated in Fig. 67 (*b*), for the ideal case. Similarly, in Fig. 67, *c*, *d*, and *e* represent respectively the conditions at the end of the second, third, and fourth quarters of the commutation period, the direction of current and its magnitude in each coil being indicated by arrows and figures. We see from these that the conditions of Fig. 63 (page 44) obtain throughout, the current in the short-circuited coils being zero at the middle of the period of commutation; so that we may conclude that the act of commutation is not altered by increasing the width of the brush.

*See *Electrician*, London, Vol. 40, p. 461; Vol. 42, p. 328.

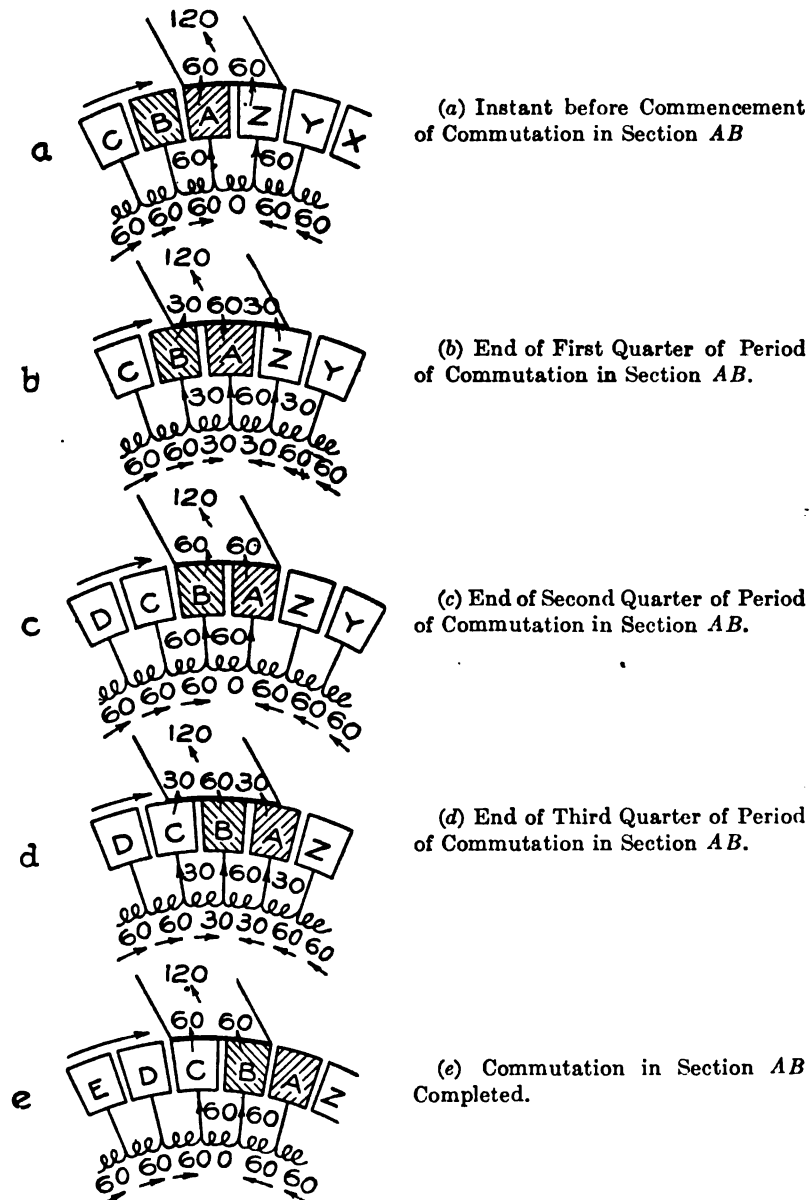


Fig. 67. Process of Commutation.—Brush Covering Two Segments



TWO 400-K. W., 600-VOLT, CROCKER-WHEELER, DIRECT-CURRENT RAILWAY GENERATORS
In Plant of Hampton Roads Traction Co.

Summary of Results. The considerations above indicated as to means for controlling the sparking at the commutators of continuous-current machines, may be summed up as follows:

(1) Keep the inductance of the armature coils low, by decreasing the number of turns per commutator segment, by saturating the teeth, and by properly shaping the pole-pieces to produce a reversal fringe.

(2) Keep the volts per segment of the commutator low by having a large number of commutator segments.

(3) Control distortion of the main flux in order to have the field under the hindward pole-horn sufficiently strong.

(4) Properly dimension and design the commutator-brushes,* brush-holders, and other brush-gear, so as to permit the shifting of the brushes to the proper position, and to enable the brushes to make contact with the commutator at all times.

(5) Keep the surface of the commutator smooth.

(6) Add special features to the machine.

To see clearly the application of most of these special features, it is desirable that we first consider another property of an armature carrying current—namely, its demagnetizing effect.

Demagnetizing Effect of Armature. To eliminate sparking at the commutator, we have seen that it is necessary to shift the brushes ahead of the neutral line in generators, and back in case of motors. The resultant effect is to produce in the armature a magnetomotive force (m. m. f.) opposed to that of the field-winding. Considering Fig. 69, wherein the brushes are supposed to be shifted to the line nn' , the remainder of the figure being as before, it is seen that the currents

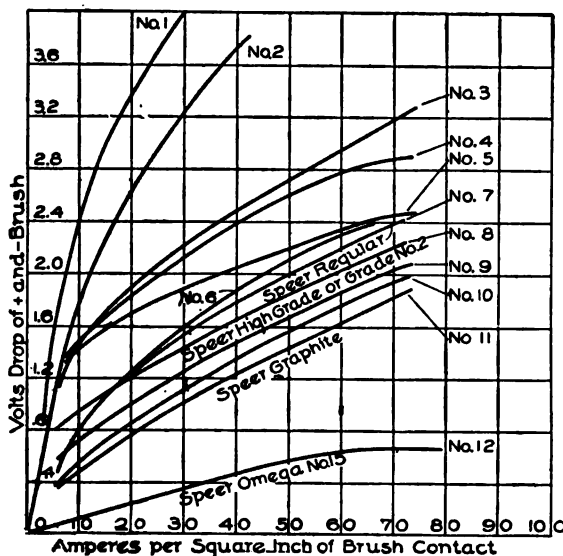


Fig. 68. Voltage-Drop Curves of Various Grades of Carbon and Graphite Brushes at Different Current-Densities.

* With respect to material and thickness, see Fig. 68.

are flowing toward the observer in the armature conductors to the left of the neutral line nn' , and from the observer in those to the right of that line. Now, suppose the two vertical lines ad and bc to be drawn across the section of the armature and through the points of commutation.

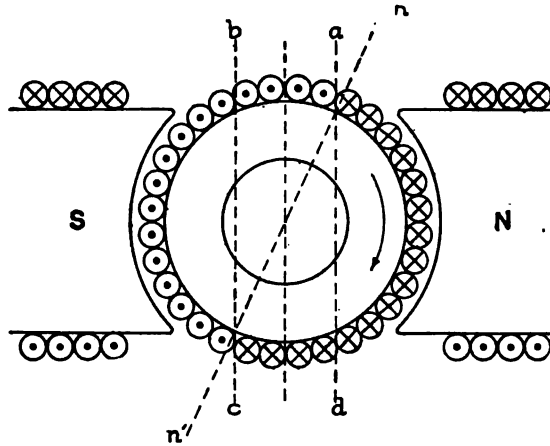


Fig. 60. Demagnetizing Action of Armature Current of Generator.

The armature conductors are thus divided into two bands, those to the right of the line ad and to the left of the line bc tending to cross-magnetize the armature, while those included between these lines produce a m. m. f. opposed to that of the main field, since the

current in these turns passes around the flux in a direction opposed to that of the field-exciting current. The breadth of the belt of demagnetizing windings is evidently proportional to the angle of lead, since it subtends double that angle. In such an armature generating 50 amperes, each conductor would carry 25 amperes, since there are two paths in parallel; and as the number of cross-magnetizing turns is 12, and the number of demagnetizing turns is 4, the "cross-ampere-turns" would be $25 \times 12 = 300$; and the number of "back ampere-turns" would be $25 \times 4 = 100$.

This demagnetizing influence, which is proportional to the angle of lead of the brushes, tends to weaken the field in general, while the cross-magnetization, proportional to the ampere-turns not included in the demagnetizing effect, tends to weaken the flux under the hindward pole-horn, and strengthen that under the forward pole-tip. Hence the impressed m. m. f. (that of the field-magnets) must be strong enough to force through the air-gap in the magnetic circuit sufficient flux to permit of sparkless commutation in spite of the demagnetizing effects. Since the cross-magnetization is responsible

for the distortion which produces sparking, it remains to consider the remedies.

Cross-Reluctance Remedies. Fig. 70 shows that increased air-gap in the magnetic circuit $HAGDH$ will diminish the cross-flux.

This method is somewhat objectionable, however, because, in order to produce the same

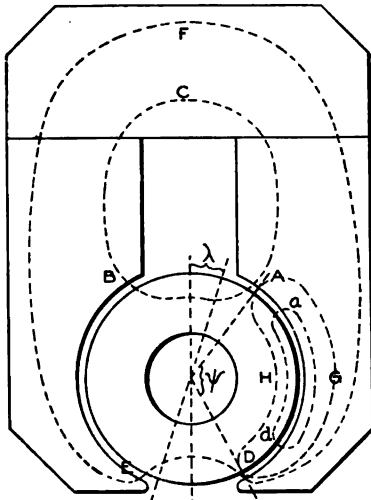


Fig. 70. Armature Interference.

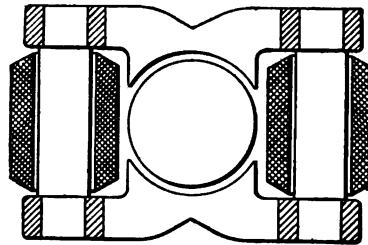


Fig. 71. Prevention of Cross-Reluctance by V-Groove in Back of Polar Mass.

flux through the field-circuit, a greater m. m. f., and hence a larger number of field-exciting turns, are required. This disadvantage may be overcome in some types of generators by forming a V-groove in the polar mass behind the face, as shown in Fig. 71.

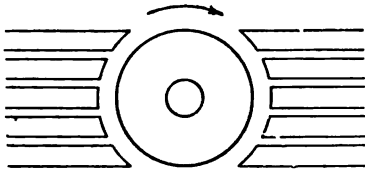


Fig. 72.

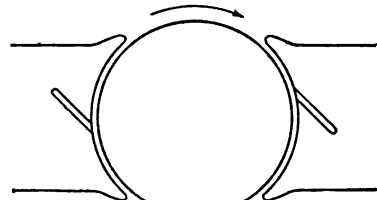


Fig. 73.

Remedies for Cross-Reluctance.—Pole-Pieces Made with Longitudinal Gaps or Oblique Slots.

Another plan is to thin down or actually separate the two halves of the circuit, and thus throttle the cross-flux. S. P. Thompson has suggested constructing the field-cores of pieces of iron with longitudinal gaps, as indicated in Fig. 72, or slotting the pole-piece obliquely as in Fig. 73, the neck of the casting here becoming highly saturated and offering large reluctance to the cross-field.

Another arrangement consists in making the forward horn of cast iron, and the rearward horn of cast steel, the joint being oblique, as indicated in Fig. 74.

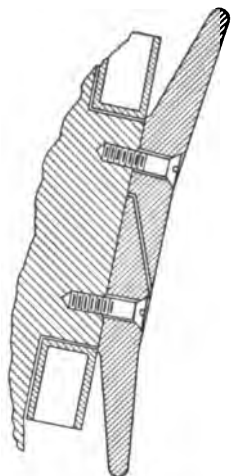


Fig. 74. Composite Pole-Shoe, Forward Horn Cast Iron; Hindward, Cast Steel. Meeting Obliquely to Minimize Magnetic Distortion at Full Load.

Cross-Compounding Remedies. Some designers provide a m. m. f. equal but opposed to the cross-magnetic m. m. f. Elihu Thomson placed a series ("compounding") coil on a separate frame surrounding the armature, and tilted it in a direction counter to the rotation so as partially to counteract the cross-flux. Swinburne suggested that a small auxiliary coil in series with the armature be wound around the pole-tip in order to maintain a field for reversal at this point (Fig. 75, a).

Menges, Mather, Swinburne, and others have advocated the use of auxiliary poles at right angles to the main poles, excited by coils in series with the armature. This feature is now embodied in the *Inter-pole* motor. S. P. Thompson proposed the use of compound winding having series and shunt coils at different angles, so that, as the armature reaction tended to shift the main flux forward,

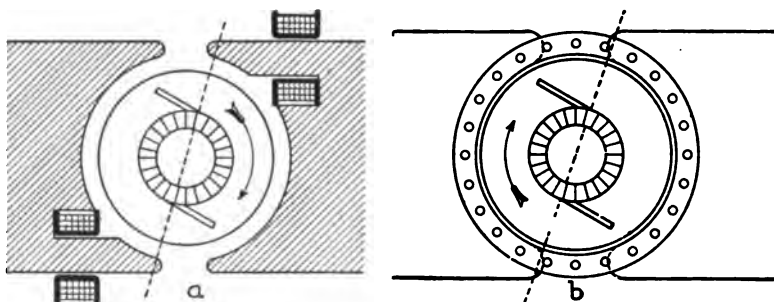


Fig. 75. Devices for Sparkless Collection of Current—(a) Swinburne; (b) Hutin and Leblanc.

the increased current in the series coils would produce a m. m. f. tending to drive it back. Menges suggested winding series turns upon the polar parts of machines with double magnetic circuits. He was the first to suggest (1884) a cross-compound winding having the auxiliary poles set to produce a flux at right angles to the main flux.

Fisher-Hinnen, Professor Forbes, Mordey, and S. P. Thompson wind these coils in a notch at the center of the pole-face. Elihu Thomson also suggested the use of *unwound* auxiliary poles at right angles to the main poles, thereby leading off the cross-flux to strengthen the main flux.

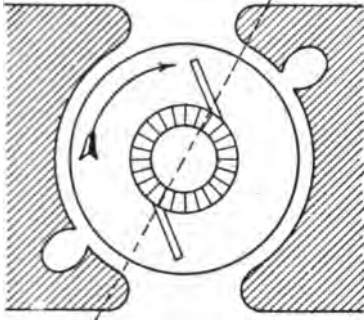


Fig. 76. Sayers' Device for Sparkless Collection of Current.

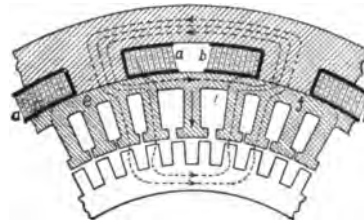


Fig. 77. Ryan's Compensating Devices.

The most complete solution was proposed independently by Professor Ryan and Fisher-Hinnen, who insert a number of coils

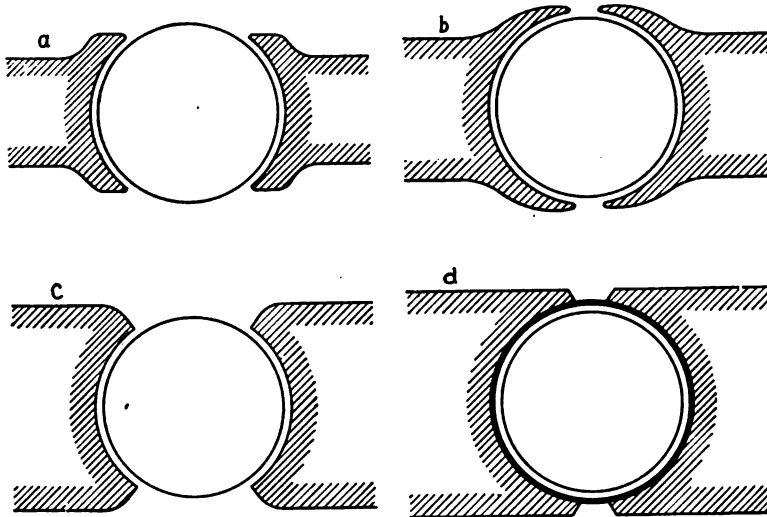


Fig. 78. Various Forms of Pole-Tips.

in slots cut in the face of the pole parallel to the shaft, the coils being connected in series with the external circuit, and constituting a stationary winding which produces a m. m. f. equal but opposed to that due to the armature, Fig. 77. This device is not extensively

employed, however, on account of the increased heating as well as complication and cost.

Hutin and Leblanc proposed the placing of rods of copper in the pole-face, which rods are short-circuited upon themselves. This

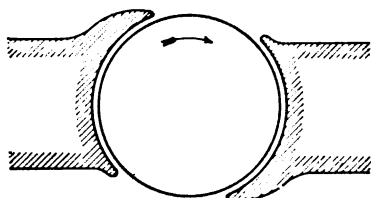


Fig. 79. Unsymmetrical Pole-Pieces Designed to Concentrate Field.

arrangement is intended to prevent oscillations in the direction of the magnetic flux at commutation. It is much used in alternating-current machines, to facilitate parallel operation (see Fig. 75, *b*).

Concentration of Field.

Sparkless commutation may also be accomplished if the field is magnetically rigid—that is, not easily distorted. This stiffness may be partially secured by properly shaping the pole-faces or by making notches in them (Fig. 76), as suggested by Sayers, thus concentrating the flux at the tip. In Fig. 78 are shown various forms of pole-tips, of which type *a* is not always good, but may be either extended as in *b*, or cut off as in *c*. An extreme arrangement, suggested by Dobrowolsky, surrounds the armature completely with iron, as in *d*.

Another scheme, proposed by M. Gravier, employed the unsymmetrical form of poles shown in Fig. 79. When the machine is working at small loads, the flux in the gap is nearly uniform; but at large loads, the distortion due to armature current forces the flux forward and saturates the forward pole-horn, thus preventing much change in its flux-density, on account of the saturation and the diminished area. Lundell combines this device with the slotted-pole method, and produces the pole shown in Fig. 80. Another plan is to make the pole-cores of laminated wrought iron or steel, to which a cast-iron pole-piece is attached.

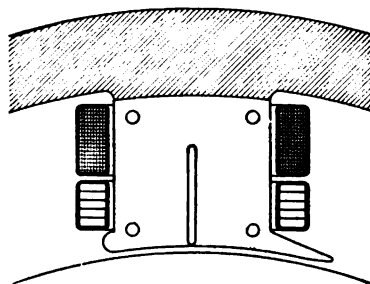


Fig. 80. Lundell's Form of Pole.

A similar effect is produced by making the poles non-concentric with the armature, as in Fig. 81. This secures a suitable fringe and

at the same time maintains a fair magnetic rigidity. Mr. C. E. L. Brown finds that inwardly projecting poles of circular cross-section, without any pole-shoes or extensions, produce excellent results in generators which deliver large current. Other devices for securing a gradual entrance of the armature conductors into the field, are to skew the hindward edge of the pole-shoe as indicated in Fig. 82; to shape the pole-shoes with polygonal ends, Fig. 83; or to provide clawed edges, Fig. 84. Some manufacturers leave out every other lamina in the pole-tips, the resulting extra saturation helping to resist the effects of armature distortion. A somewhat similar device is that patented by Marshall, which consists in attaching to the pole-piece groups of short, laminated iron plates with narrow spaces between them, thus reducing the net area of the shoe, while preserving the same effective area.

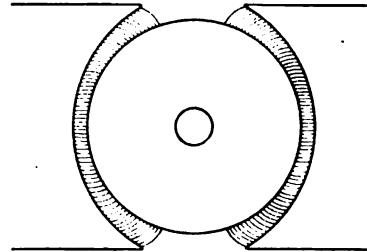


Fig. 81. Non-Concentric Poles.

Self-Compensating Armatures. The devices of Swinburne and Mordey, which relate to chord winding, have met with considerable

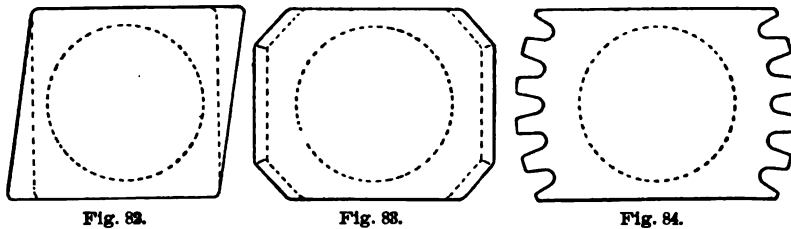


Fig. 82.

Fig. 83.

Fig. 84.

Devices for Securing Gradual Entrance of Armature Conductors into Field.

success. The most prominent of these methods is that of Sayers, who connects the commutator-bars to the armature winding through auxiliary compensating coils. One end of each commutator coil, Fig. 85, is attached to the junction between two main armature coils, and the other end is connected to a commutator segment. The armature and commutator coils are represented while short-circuited by the brush, a rapid reversal of current being produced by the commutator coil and auxiliary pole. With this method of winding, the

brushes may be given a backward lead, thus making the generator self-compounding without a series field-coil.

This completes the list of special features that may be added to generators or motors to eliminate sparking at the commutator; but most of these methods are not likely to be employed, on account of increased complications and reduced efficiency. In the largest

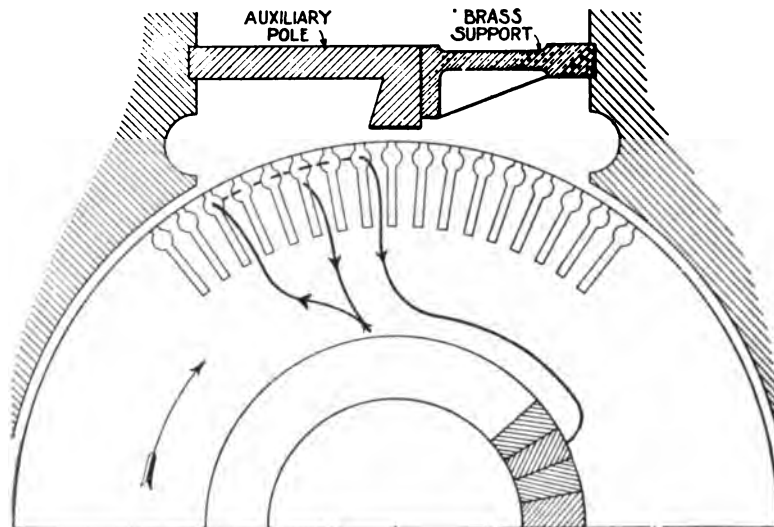


Fig. 85. Sayers Compensating Winding, with Commutation Coils.

machines built by the best manufacturers, none of these special features are present, because it is found that the heating limit of the machine is usually reached before sparking occurs. One prominent designer pays no attention to armature reaction, but relies upon a large number of commutator segments to keep the e. m. f. per segment at a very low figure, also minimizing the self-inductance of each armature coil by making it of few turns and of short length parallel to the shaft. For medium sizes or high-speed work, this design is now much used, especially where large distorting effects are present.

Conclusions. The special points to be observed in order to prevent sparking at the commutator may therefore be stated as follows:

1. The armature ampere-turns per pole should not exceed certain definite values in machines of a given type. If the volts per commutator segment are 5 or less, the armature ampere-conductors should not exceed

20,000 per pole; while with 10 volts per segment, the ampere-conductors should not exceed 10,000.

2. Long air-gaps are unnecessary if the armature teeth are highly saturated—that is, have a flux-density of from 20,000 to 23,000 apparent lines* per square centimeter, or 125,000 to 150,000 apparent lines per square inch, both of the injurious effects of armature reaction being diminished.

3. Armatures should be as short as possible in order to reduce the self-inductance of the armature coils.

4. Number of volts per commutator segment should be low.

5. Inductance of the short-circuited coils should be low compared with brush-contact resistance, and the current-density in carbon brushes should be about 35 amperes per square inch.

Dead Turns.

On account of the various internal reactions present in the armature, the terminal voltage is not quite proportional to the speed with constant field-current. Inasmuch as the machine acts as though some of

its speed were ineffective, the name *dead turns* has been given to those revolutions by which the actual speed at any output exceeds that determined by strict proportionality.

Spurious Resistance. There is present in every rotating armature an apparent resistance proportional to the speed, due to the self-induction of the armature, as first pointed out by Cabanellas. It cannot be reduced by dividing the armature conductors into a greater number of segments, but can be made less by decreasing the number of conductors and increasing the cross-section of iron in the magnetic circuit. Its value is lessened by the introduction of a counter-e. m. f. aiding the commutation of the current, as previously explained.

Eddy Currents. In discussing the magnetic circuit, it was shown that parasitic currents may be produced in the iron parts

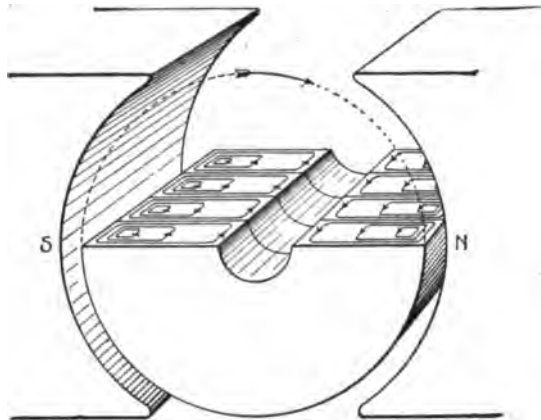
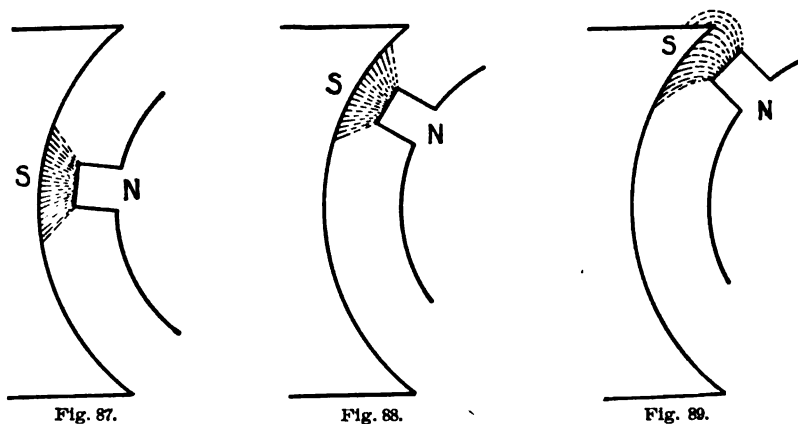


Fig. 86. Eddy Currents in Core-Discs.

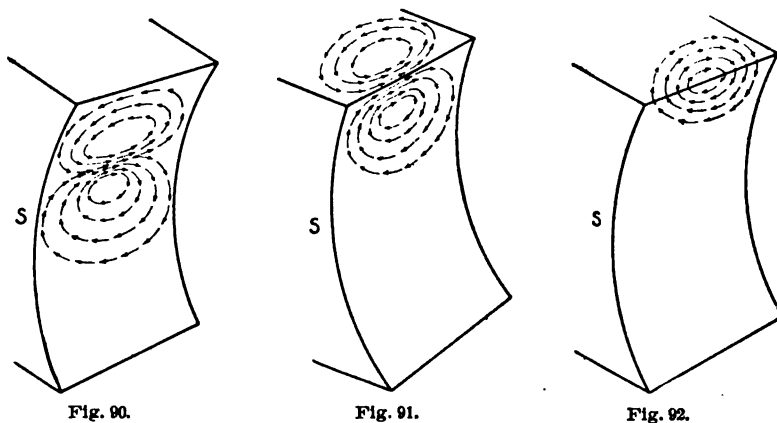
* By *apparent lines per square centimeter in the teeth* is meant the flux-density which would be present in the teeth if all the flux issuing from the poles entered the armature core through the teeth.

of generators if any of these parts form closed electrical circuits and cut flux. In the armature, the iron core rotates in a magnetic field;



Alteration of Magnetic Field Due to Movement of Mass of Iron in Armature.

eddy currents are set up in this core, as shown in Fig. 86, and unless prevented from flowing, these currents will lower the efficiency of the machine. Eddy currents will also be produced in the pole-faces,



Eddy Currents Induced in Pole-Pieces by Movement of Masses of Iron.

due to the variation of the magnetic flux, as shown in Figs. 87-92; and they may in addition manifest themselves in the armature conductors if the latter are large.

In all cases where eddy currents are likely to be large, the circuits

affected are laminated so that the plane of lamination cuts across the path of this parasitic current.

Drag on Armature Conductors. A conductor carrying a current is surrounded by a magnetic field, as shown on page 2. If, now, such a conductor be placed in a uniform magnetic field—as, for example, between a large north pole and a large south pole—a compound field will result, having the distorted appearance shown in Fig. 93. The direction of the mechanical force exerted may be determined by supposing that the flux acts as a bundle of elastic cords tending to

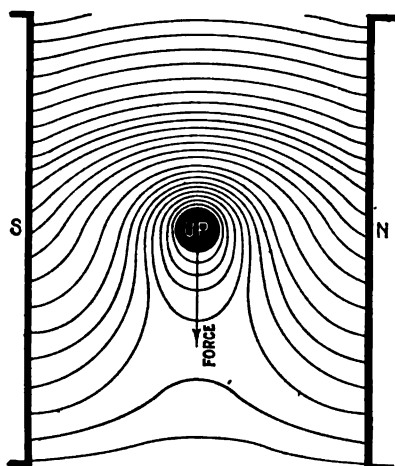


Fig. 93. Magnetic Lines Due to Conductor Carrying Current Placed in Magnetic Field.

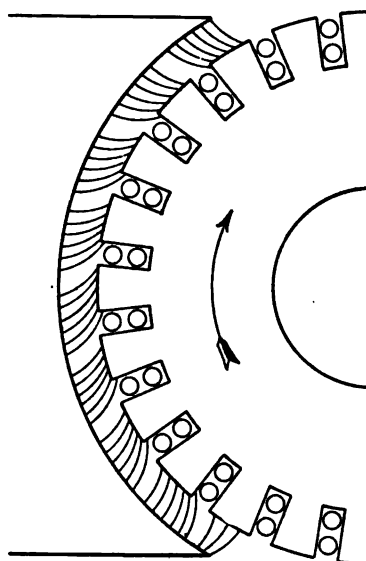


Fig. 94. Magnetic Field of Slotted Armature.

shorten themselves. As a matter of fact, there is tension in the direction of the flux, and stress at right angles to it, proportional at every point to the square of the flux-density. A conductor in which current is supposed to be flowing toward the observer will therefore be urged in the direction of the arrow, Fig. 93; so that in every dynamo-electric machine the current generated produces a mechanical reaction which tends to stop the motion producing them.

If the conductors are imbedded in slots or holes in the armature core, Fig. 94, it is found that the drag comes upon the iron, the magnetic field being distorted as shown. In fact, the flux no longer directly cuts the conductors, but, as it were, flashes from tooth to

tooth. In addition to thus relieving the conductors of the drag effect, the teeth permit a much smaller air-gap to be used, sometimes reducing it to a mere mechanical clearance.

Stray-Power. In all practical machines there is a difference between the input and the output. In electrical machines, this discrepancy is caused by the following reactions:

1. Armature-resistance drop producing I^2R effects.
2. Friction of bearings and brushes.
3. Air-friction of the rotating armature.
4. Hysteresis in the armature core.
5. Eddy currents in the armature core, conductors, and polar projections.
6. Energy is also consumed in the field winding, due to I^2R effects.

Nos. 2, 3, 4, and 5 are grouped under the head of *stray power losses*, being from 40 to 60 per cent of the total loss. No. 3 is small, except in those cases where the armature spider is provided with fans to aid ventilation, and where special ventilating ducts are provided in the armature, as in most modern machines. No. 4 is by no means negligible, but never adds more than 1 per cent to the driving power. No. 5 is the most important of all, especially in large machines. It makes its presence felt even in the metal of the shaft, and there will be power wasted if flux leaks through this portion.



FIVE-STAGE MOTOR-DRIVEN TURBINE PUMP.
Adapted to Heads up to 760 Feet.

DIRECT-CURRENT MOTORS

Comparison between Dynamos and Motors. The dynamo is a machine for the conversion of mechanical into electrical energy; conversely, the electric motor converts electrical energy into mechanical work. The electrical energy delivered by the dynamo must be obtained from a steam engine, water-wheel, or other power; and the mechanical power obtained from the electric motor comes from the energy of the current flowing through its armature. The two machines are exactly complementary; and, in the case of direct-current apparatus, we shall see that the same structure can be used for either service. The differences that are found in practice are largely mechanical, and arise chiefly from the conditions under which the motor must work.

The study of the electric motor, therefore, begins with a knowledge of the dynamo; and before reading the following pages, the student should be sure that he understands fully the fundamental principles and mechanical details of Dynamo-Electric Machinery.

Force on a Conductor Carrying a Current. Fig. 1 represents a wire lying in a magnetic field, and carrying no current. If the polar surfaces of the field are large and close together, the magnetic lines pass straight from one to the other; they are not distorted, whether the wire is at rest or in motion. This is the condition in the air-gap of a dynamo or motor when no current is flowing in the

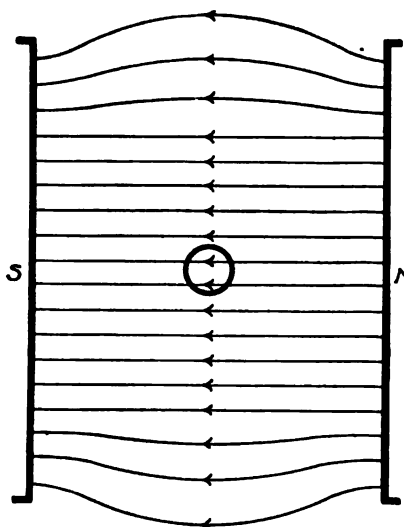


Fig. 1. Conductor Carrying No Current, in a Magnetic Field.

armature conductors. The rotation of the armature in the magnetic field generates an electromotive force, but there is no mechanical force upon the conductors due to this action in itself. When, however, a current flows, it sets up a magnetic field of its own about the conductor, as shown in Fig. 2; and this field distorts the original field in which the conductor lies, making the magnetic lines denser on one side and less dense on the other. This is shown in Fig. 3.

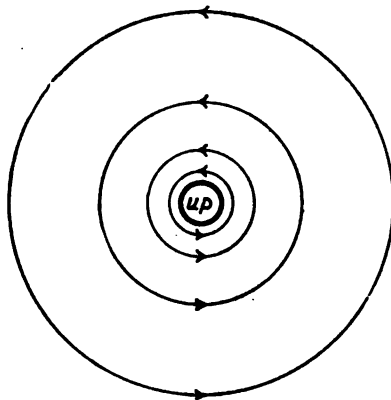


Fig. 2. Magnetic Field about a Conductor Carrying a Current.

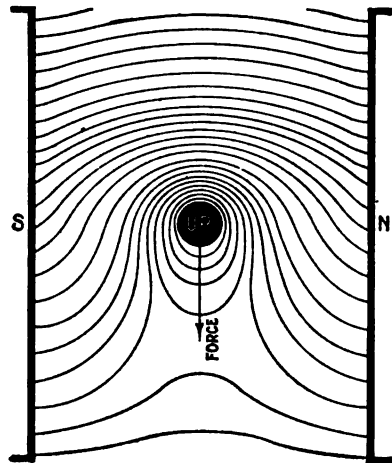
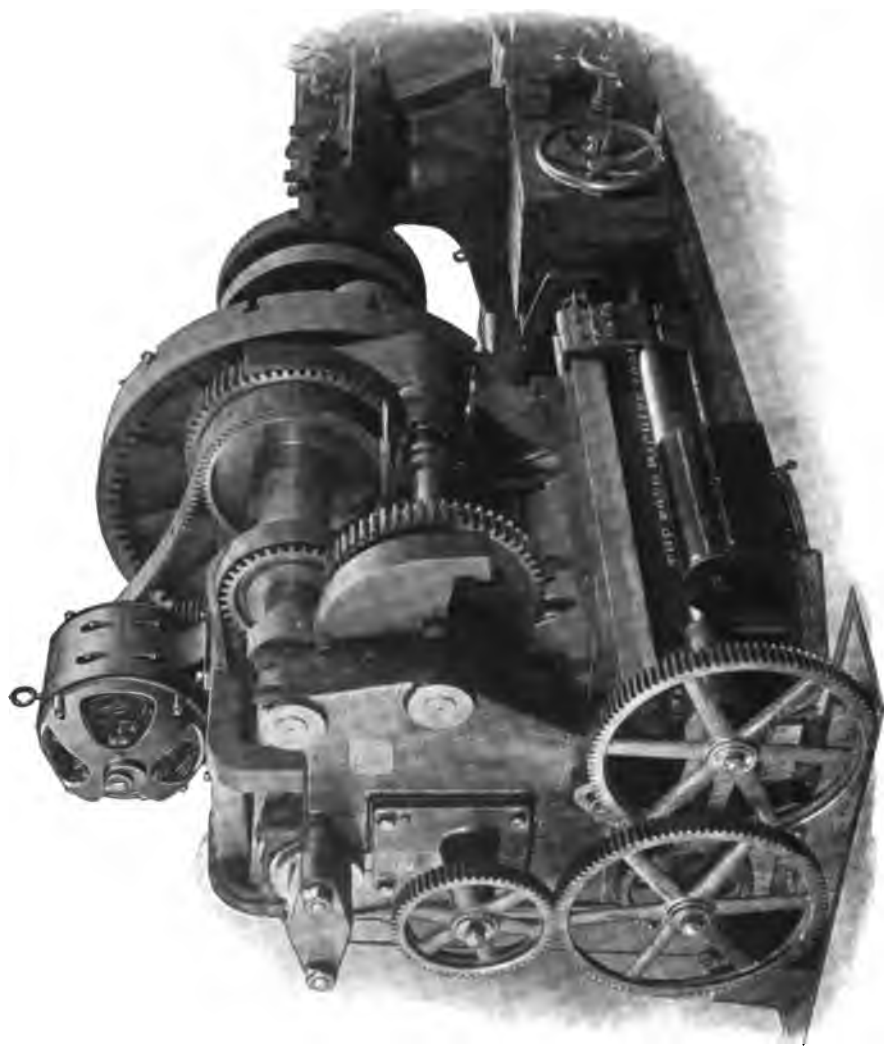


Fig. 3. Magnetic Field around Conductor in Dynamo or Motor Air-Gap.

Since the magnetic lines of a field endeavor to straighten and shorten themselves, the result of this distribution is a force upon the wire, pushing it in the direction of the arrow; and this is the principle of the electric motor. As in the dynamo, there are required: (1) a magnetic field; (2) a conductor lying perpendicular to it; and (3) provision for motion of the conductor across the field, in a direction perpendicular both to itself and to the field.

Fleming's Rule. The relation between the directions of the force, current, and magnetic lines can be most easily remembered by what is known as *Fleming's Rule*. Extend the forefinger, middle finger, and thumb, at right angles to one another; for example, the forefinger directly forward, the middle finger sideways, and the thumb upwards. Then if the forefinger represents the direction of the magnetic lines (that is, from the N pole through the air to the S pole), the middle finger will represent the direction of the current, and



72-INCH LATHE DRIVEN BY 15 H.P. THOMPSON-RYAN MOTOR.
80-1750 Rev. per Minute.
Ridgway Dynamo and Engine Co

the thumb the direction of the motion. The right hand is to be used for the case of the dynamo, the left hand for the case of the motor.

Barlow's Wheel. An illustration of this principle is found in the simple electric motor invented by Peter Barlow in 1823, and illustrated in Fig. 4. A star-shaped metal wheel, usually of copper, rotates with its lowest points dipping into a little insulated pool of mercury. The wheel is connected through its bearings with one pole of a battery, the mercury to the other pole, the current flowing radially upward or downward through the wheel. When a horseshoe magnet is brought over the wheel, so that the portion carrying the current lies between the magnet-poles, the wheel revolves briskly, the direction of rotation changing whenever the direction of the current or the magnetic field is reversed.



Fig. 4. Barlow's Wheel.

Magnitude of the Force on a Wire Carrying a Current. If the magnetic field has one line of force per square centimeter, and one absolute electromagnetic unit of current (10 amperes) is flowing in the conductor, the force upon each linear centimeter of the conductor will be one dyne. Hence, since the effects are directly proportional to the quantities involved, a wire L centimeters long, lying across a field of B lines per square centimeter, and carrying a current of I amperes, will be subjected to a force of:

$$L B \frac{I}{10} \text{ dynes.}$$

This is practically a corollary of the definition of the ampere in electromagnetic measure.*

This expression may be reduced to the inch and pound units which are more common in American shop practice, by noting that one inch equals 2.54 centimeters; that one dyne is $\frac{1}{9.80665}$ of the weight of a gram, nearly; and that 453.59 grams, or nearly 445,000 dynes, equal the weight of one pound. Hence the force F' upon

*Consult S. P. Thompson's *Elementary Lessons in Electricity and Magnetism*, or any similar textbook on Electricity.

a wire L'' inches long, lying perpendicularly across a field of B'' lines per square inch, and carrying a current of I amperes, will be:

$$2.54 L'' + \frac{B''}{(2.54)^2} \times \frac{I}{10} \text{ dynes;}$$

or,

$$F' = \frac{L'' B'' I}{2.54 \times 445,000 \times 10} = \frac{L'' B'' I}{11,303,000} \text{ pounds, approximately.}$$

Upon N similar wires, the force will be N times as great.

Example. Fourteen hundred conductors of a certain large armature, each 11 inches long, lie in magnetic fields of 42,000 lines per square inch. What is the total drag upon them when each carries a current of 60 amperes?

Solution. The force is:

$$\frac{1,400 \times 11 \times 42,000 \times 60}{11,303,000} = 4,318 \text{ pounds, nearly.}$$

EXAMPLE FOR PRACTICE

Under the poles of a certain 25-kilowatt machine, there are 225 conductors, each $6\frac{1}{2}$ inches long, in magnetic fields of 40,000 lines per square inch. What current must flow in each conductor in order to give a total rotative force of 200 pounds?

Ans. 38.64 amperes, nearly.

In considering questions like the above, it is important to observe that only the conductors lying beneath the poles are subjected to these forces; and that the current in the individual conductors is not the full current of the machine, but only a fraction of it—one-half in the case of bipolar and wave-wound armatures; and one-fourth, one-sixth, or less, in the case of lap-wound armatures, according as the machine has four, six, or more poles.

It will now be clear that the driving force upon a dynamo armature must be increased in direct proportion to the load put upon the machine, and that the force causing a motor armature to rotate also depends on the current in it. The dynamo current is determined by Ohm's law, and the engine or water-wheel governor takes care of the power supply; but the way in which the electric motor adapts itself to the variations in its work, taking always just the necessary current for the work in hand, is not so clear at first sight. The explanation involves a most important property of the machine, known as the *counter-electromotive force*.

Counter-E.M.F. of a Motor. Since the armature wires rotate in magnetic fields, exactly as in the case of the dynamo, all the conditions for the generation of E.M.F. are fulfilled; and we should expect the motor armature to generate an E.M.F. accordingly, while in motion. The existence of such an E.M.F., and its direction, may be shown by the following experiment:

Take a small shunt-wound motor, and connect it as for ordinary running, but with the addition of a suitable incandescent lamp *L* and an ammeter *A* across the arma-

ture terminals, as shown in Fig. 5. When the motor is running, the lamp will glow, obviously supplied from the line; and the ammeter will show the direction of the current through it, as indicated by the arrow at *L*. The dotted arrows show the direction of the current in the other parts of the circuit. Now let the double-pole switch be opened; so far as the electrical conditions are concerned, the circuits may then be represented by Fig. 6; and the machine will run for a little while as a dynamo, driven by the energy stored in the rotating armature. The lamp still glows, and the ammeter shows that the current through it is in the original di-

rection, dying out as the armature slows down to rest. Since the source of E.M.F. in the system is the revolving armature, and the direction of the current through the ammeter is known, it follows that in the other parts of the circuit the current must flow as indicated by the dotted arrows in Fig. 6. The reversal of the current in the armature can be shown directly by putting a second ammeter into the armature circuit, as indicated at *B*, Fig. 6, but the experiment can be performed equally well without it.

This experiment is very instructive if performed with a motor

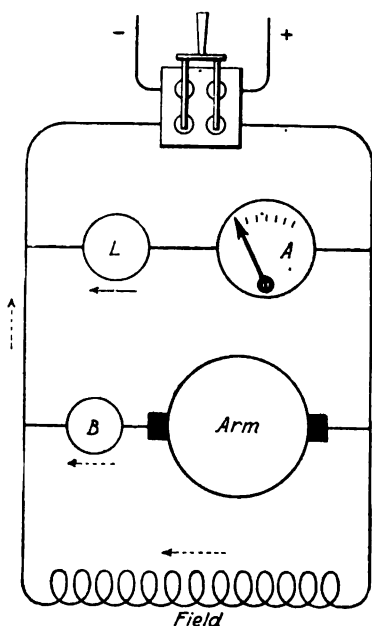


Fig. 5. Motor Connections to Show Counter-E.M.F.

of several horse-power. The experimenter should prevent the arm of the starting rheostat from flying back until the armature has entirely ceased to revolve.

A comparison of Figs. 5 and 6 now brings the conclusion that the direction of the current in the various parts of the circuit must be due to the existence of an E.M.F. in the revolving motor armature which is opposite in direction to the line E.M.F., and hence opposes the flow of current through the armature. For this reason it is

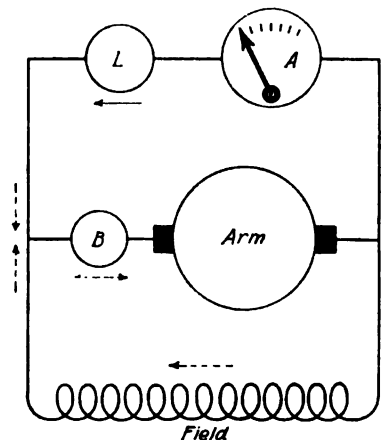


Fig. 6. Currents in Motor Circuits after Opening Main Switch.

called the *counter-E.M.F.* The electrical difference, therefore, between a dynamo and a motor is that in the dynamo the current flows *with* the E.M.F. of the armature, while in the motor it flows *against* it.

Fundamental Motor Equation.

From the above it follows that the current through the revolving motor armature is always less than the value obtained by simple calculation from Ohm's law, because E , the line E.M.F., is partially neutralized by e , the opposing counter-E.M.F. Hence the fundamental motor equation may be written:

$$I = \frac{E - e}{R}, \quad \dots \dots \dots (1)$$

in which I represents the current through the armature, and R the resistance of the armature circuit—armature, brush gear, and any other resistance that may be present.

The counter-E.M.F. is not readily measured; it is best calculated from Equation 1 with a knowledge of the other three quantities, which are easily measurable.

Example. A certain motor armature with its brush gear has a resistance of 0.188 ohm; and when running at a certain speed, takes a current of 55 amperes from a 220-volt line. What counter-E. M. F. is developed under these conditions?

Solution. Substituting the given values in Equation 1, we have:

$$55 = \frac{220 - e}{0.188};$$

whence,

$$e = 209.66 \text{ volts.}$$

EXAMPLE FOR PRACTICE

What current will flow through the above armature when its counter-E.M.F. is nine-tenths of the line voltage?

ANS. 117 amperes, nearly.

From these considerations it is plain that in the absence of other resistance in the armature circuit than that of the armature itself, a slight change in the counter-E.M.F. may make a great difference in the strength of the current flowing. Further, since the figures are taken from actual machines, it is to be noted that under ordinary running conditions the counter-E.M.F. rises well up toward the value of the line E.M.F. It can of course never quite equal the line E.M.F., for in that case no current would flow; and even when running without load, the friction and electrical losses of the motor absorb some power, so that a small fraction of the full-load current will flow, though the armature delivers no power at the pulley.

Efficiency and Losses. The energy-losses of the motor are the same as those of the dynamo, and may be classified under two heads:

Electrical Losses:

- (a) I^2R losses in armature conductors and brush gear.
- (b) I^2R losses in field windings.

Stray-Power Losses:

- (c) Friction: of bearings, brushes, and air-currents.
- (d) Iron losses: eddy currents in armature core, teeth, and magnet-poles; hysteresis in armature core and teeth.
- (e) Commutator losses: wasteful currents in coils during commutation.
- (f) Eddy currents in armature conductors.

The electrical losses (a) and (b) are measurable without much trouble; the others are very difficult to obtain separately, and are usually taken together under the general name *stray power*. For shunt motors, the field I^2R loss is independent of the load; the armature I^2R , of course, varies with the load. In the series motor, both field and armature I^2R vary with the load, since the same current passes through both. The stray-power loss is nearly constant for ordinary operating conditions, though it increases slightly with the speed of the armature.

The commercial efficiency η of a motor is simply the fraction of the power supplied that is available at the shaft; that is, it is the

ratio of the power delivered to the power supplied; or, in the form of an equation:

$$\eta = \text{Efficiency} = \frac{\text{Output}}{\text{Input}} = \frac{\text{Input} - \text{Losses}}{\text{Input}} \quad \dots (2)$$

The following table shows average values for the commercial efficiency of ordinary motors of various sizes, at full load:

TABLE I
Commercial Efficiency of Ordinary Motors

FULL LOAD H.P.	EFFICIENCY (Per Cent)
0.02 (Fans)	30
0.05 "	42
0.1	50
0.5	63
1.	70
5.	82
10.	85
25.	88
50.	89.5
100.	91
200.	92.5

The low figures for small motors are caused by disproportionately large field I^2R and friction losses.

Variation of Efficiency with Load. The efficiency varies with the load, because some of the losses are constant and some variable, the chief variable being the armature I^2R . When the motor is running idle, the current is small, and all its energy goes to supply the losses, the commercial efficiency being therefore zero. As the motor is loaded, the output at first increases faster than the losses, and the efficiency rises rapidly, reaching a maximum at a certain load which depends on the design of the machine. When the load is very heavy, the great increase in the armature I^2R causes the efficiency to fall again.

The efficiency is a maximum when the constant and variable losses are equal—for example, in the case of a shunt motor, when the armature I^2R loss equals the sum of the stray-power and field I^2R losses.* Since the distribution of the losses may be controlled by

* This proposition may be proved by algebraic methods, as follows:

Denoting by S the sum of the field I^2R loss and the stray power, the efficiency may be written:

$$\eta = \text{Efficiency} = \frac{EI}{EI} - \frac{I^2R}{EI} - \frac{S}{EI} = 1 - \left(\frac{IR}{E} + \frac{S}{EI} \right).$$

the designer within fairly wide limits, it follows that a motor (or a dynamo) may be designed to show its maximum efficiency at any specified fraction of its full load, or even at overload, though the latter is unusual. Motors should be designed to have their maximum efficiency with the load at which they are most used. An ordinary shop motor should show a maximum at about 75 per cent of its full rated load; a street-railway motor, at about two-thirds of the maximum power it is expected to develop (see Fig. 33); a fan motor, at its full load; and so on. A motor with large constant losses and small variable losses will have a low efficiency at light loads, and a high one at full load; while a machine with small constant and large variable losses will have a much higher efficiency at light loads than at full load. The most important point is not the full-load efficiency, but rather the maximum efficiency, coupled with another figure which we may call the *all-day efficiency*.

All-Day Efficiency. This is a matter of some importance in practice. It is simply the ratio between the work obtained from the motor during the day, and the energy taken from the line in the same time.

The difference between the performances of different machines in this respect, is best shown by an example. Suppose we have two 100-horse-power motors, motor *A* having constant losses of 2,700 watts, and armature I^2R losses of 6,400 watts; and motor *B* having constant losses of 4,800 watts, and armature I^2R losses of 3,200 watts. Suppose them to run through a 9-hour day, and that

For maximum efficiency, it is plain that $\frac{IR}{E} + \frac{S}{EI}$ must be a minimum; or, since E is a constant, that $IR + \frac{S}{I}$ must be a minimum. The sum of these two terms will be large when I is either very large or very small, and the problem is to determine the particular value of I for which it will be smallest. Denoting the sum by k , we may write:

$$IR + \frac{S}{I} = k, \dots\dots\dots (a)$$

which is a quadratic equation in I . Solving this by ordinary algebra gives:

$$I = \frac{k}{2R} + \frac{1}{2R} \sqrt{k^2 - 4RS} \dots\dots\dots (b)$$

Now, since a negative quantity cannot have a square root, the quantity under the radical sign cannot be less than zero, and therefore the smallest value k can have will be determined from the equation:

$$k^2 - 4RS = 0. \dots\dots\dots (c)$$

Inserting in (a) the value of k obtained from (c), and reducing, gives as the final result $IR = S$; or, in other words, when a motor is working at its highest efficiency, the armature current is such as to make the variable losses just equal to the constant losses.

they run for 2 hours at quarter-load, 4 hours at half-load, and 3 hours fully loaded; let us calculate the energy actually delivered, and the energy taken from the line. Remembering that 1 H.P. = 746 watts, and that the I^2R loss varies as the square of the current, we have, for motor *A*, the following:

<i>Constant Losses:</i>	2,700 watts for 9 hours,	24,300 watt-hours.
<i>I R Losses:</i>	$\frac{1}{16}$ of 6,400 watts for 2 hours,	800 "
	$\frac{1}{4}$ of 6,400 watts for 4 hours,	6,400 "
	6,400 watts for 3 hours,	19,200 "
<i>Output:</i>	$\frac{1}{4}$ of 74,600 watts for 2 hours,	37,300 "
	$\frac{1}{2}$ of 74,600 watts for 4 hours,	149,200 "
	74,600 watts for 3 hours	223,800 "
Input for the day:		461,000 watt-hours.

The all-day efficiency is therefore:

$$\frac{\text{Output}}{\text{Input}} = \frac{410,300}{461,000} = 89 \text{ per cent}$$

For motor *B*, we have:

<i>Constant Losses:</i>	4,800 watts for 9 hours,	43,200 watt-hours.
<i>I²R Losses:</i>	$\frac{1}{16}$ of 3,200 watts for 2 hours,	400 "
	$\frac{1}{4}$ of 3,200 watts for 4 hours,	3,200 "
	3,200 watts for 3 hours,	9,600 "
<i>Output:</i>	as for motor <i>A</i> ,	410,300 "
Input for the day:		466,700 watt-hours.

Hence the all-day efficiency is:

$$\frac{410,300}{466,700} = 87.9 \text{ per cent.}$$

Thus, although motor *B* has a higher full-load efficiency than motor *A* (90.3 per cent as compared with 89.1 per cent), the latter returns the larger percentage of the energy put into it during the day, the difference being 5,700 watt-hours, or 5.7 kilowatt-hours in favor of *A*. It is thus seen to be a matter of some importance to keep the constant losses down to the lowest point consistent with satisfactory operation in other respects; and machines should be selected by the purchaser with reference to this point, as well as for full-load efficiency. For this reason the efficiency values at different loads may vary several per cent in motors of different but equally good design; and the figures in the preceding efficiency table must be regarded as only approximate. Most shop and factory motors are subjected to very variable loads; and the average load of a large

number of motors in a given plant will often be found to be considerably less than 25 per cent of the total rated capacity of the motors in circuit. With motors designed upon the lines mentioned above, it may be said that the saving at average day loads would range from 4 per cent to 10 per cent in the larger motors (from 60 to 120 horsepower), up to a saving of 8 per cent to 15 per cent in the smaller motors.*

EXAMPLE FOR PRACTICE

Suppose a 100-horse-power motor were designed so as to have constant losses of 6,400 watts and armature I^2R losses of 2,700 watts, and that it works under the same conditions as those given for motor *A* in the preceding example. What would its all-day efficiency be, and how much more energy would it take from the lines in one day than motor *A*? Ans. 85.7 per cent; 18 + kilowatt-hours.

Current Required by Motors. The value of the full-load current is usually stamped upon the name-plate of the machine. If not, it can be approximately found from the rated output by assuming a value for the efficiency.

Example. What current will be required by a 220-volt, 15-horse-power motor?

Solution. From Table I (p. 8), the efficiency may be taken as 86 per cent. The output is:

$$15 \times 746 = 11,190 \text{ watts.}$$

The input is:

$$\frac{11,190}{0.86} = 13,012 \text{ watts.}$$

The current is therefore:

$$\frac{13,012 \text{ watts}}{220 \text{ volts}} = 59.1 \text{ amperes.}$$

EXAMPLES FOR PRACTICE

1. A 50-horse-power motor is connected to a 500-volt line which will carry 60 amperes. Can the motor be operated at full load? Ans. No.

2. Assuming an efficiency of 88 per cent, what is the maximum power that can be obtained from the above motor without overloading the line? Ans. 35.4 horse-power, nearly.

*Hobart, *Electric Motors*, 1904.

Effect of Counter-E.M.F. on Efficiency. At first sight it might appear that the counter-E.M.F. is merely an incident of operation, or at least a hindrance to the best performance of the machine; but a more careful study of the question shows that it is an essential factor in the economy of the motor. This can be most clearly shown by taking the artificially simple case of a motor whose only losses are the armature I^2R . This would be very nearly realized by a frictionless magneto-motor. Its efficiency η would be:

$$\eta = \frac{\text{Input} - \text{Losses}}{\text{Input}} = \frac{EI - I^2R}{EI} = \frac{E - IR}{E}. \quad \dots (3)$$

But,

$$I = \frac{E - e}{R};$$

whence,

$$IR = E - e.$$

Substituting this value of IR in Equation 3, we have:

$$\eta = \frac{E - (E - e)}{E} = \frac{e}{E}. \quad \dots \dots \dots (4)$$

That is, the efficiency is directly proportional to the counter-E.M.F.

This proposition is known as *Siemens' Law of Efficiency*. It should not be understood as implying anything concerning the output. The current taken by the motor diminishes as the counter-E.M.F. rises; and the power delivered also diminishes as the armature approaches full speed. But the equation does mean that the power delivered per ampere taken from the line is greater as the value of e approaches E ; and therefore, though the actual power delivered is less, the available *percentage* of the line energy is greater than if the actual output were larger. For this reason it is entirely possible to operate a motor beyond its rated capacity, though at a reduced efficiency, the permissible amount and duration of the overload depending chiefly on the time required for the increased losses to heat up the machine dangerously.

In the actual motor, where other losses enter, the case is not quite so simple and direct as the above; but the difference is small, the complete equation being:

$$\eta = \frac{E - I \left(\frac{S}{I} + R \right)}{E}$$

in which S is the sum of the field IR and the stray power, as on page

8. The fraction $\frac{S}{I}$ is only a few per cent of E , in ordinary running under load, so that the Siemens law holds, except for small values of I —that is, for light loads.

So it follows that the counter-E.M.F. is a valuable property of the motor, to be cultivated rather than ignored or eliminated; and the lack of success of early types of motors was in part due to a failure to realize this. In other words, the motor should be designed and operated to generate an E.M.F. exactly like a dynamo; and the formula for efficiency shows that the electrical and mechanical losses should be kept as small as practicable. The requirements for dynamos and motors are therefore the same, and it should now be clear that they must be designed along the same electrical lines. Consequently they are interchangeable.

The fact that a dynamo will transmit power to a similar machine as a motor is said to have been brought to light by a Paris workman in 1873, who accidentally connected the wires of an idle dynamo to the terminals of one in operation, whereupon the motionless armature immediately started up at full speed. The discovery of the general principle of interchangeability, however, dates back to 1852, and perhaps earlier.*

Torque. The torque of a motor is the turning moment or twist exerted upon the shaft. Grasp the pulley of a small motor firmly in the hand, and close the switch; a strong twisting action will be felt, which will set the armature in rapid rotation when freed. With the armature stationary, the torque is sometimes called *static torque*, to distinguish it from the *running torque* of the rotating armature, available at the pulley; the latter is less than the former by the amount necessary to overcome armature friction and core losses.

Since torque is caused by a force acting at the end of a lever arm, it is measured by the product of the force and the length of the arm—for example, by the product of the working pull of the belt and the radius of the pulley; or by the force upon the armature wires, multiplied by their average distance from the axis of the shaft. This product is generally expressed in *pound-feet*, which term denotes the

*S. P. Thompson, *Dynamo-Electric Machinery*, Edition of 1888, p. 13.

pull in pounds multiplied by the length of the lever arm in feet.* Thus a torque of 60 pound-feet may represent a working belt-pull of 60 pounds on a pulley 1 foot in radius, or a pull of 72 pounds on a pulley whose diameter is 20 inches, or any other combination of force and arm whose product is 60 pound-feet. For simplicity, torque is sometimes expressed in pounds only, a radius of one foot being understood or implied; but this is liable to cause confusion, because torque is not a force, but the moment of a force, and the radius of its action should always be given.

EXAMPLE FOR PRACTICE

If a motor has a torque of 40 pound-feet, what pull will be exerted at the rim of a pulley 16 inches in diameter?

Ans. 60 pounds.

The torque of a motor may be measured by means of a Prony or friction brake. The arrangement of the apparatus is shown in

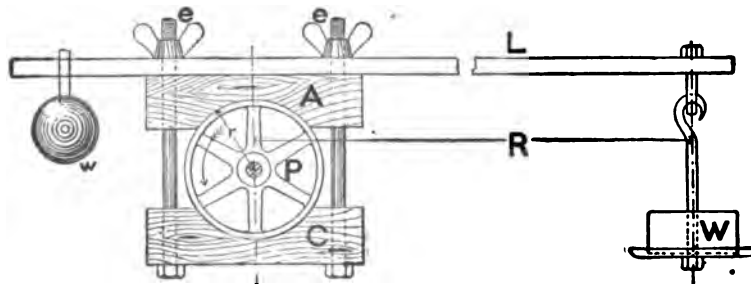


Fig. 7. Friction Brake.

Fig. 7. P is the motor pulley, A and C blocks of hardwood clamped against it, the pressure being regulated by the wing-nuts e . The lever L , which may be of any convenient length, is counterbalanced by the weight w . When the pulley rotates in the direction of the arrow, the friction on the blocks tends to raise the weight W ; and by adjusting the pressure on the blocks and varying W , a balance may be obtained, so that W when hanging free just neutralizes the tendency of the lever L to revolve. The torque of the motor is then $W \times R$, where R is the perpendicular distance from the axis of the shaft to the line of support of W .

*The term *foot-pounds* should not be used in this connection, for the foot-pound is a commonly used unit of work, and torque by itself is not work.

To find the torque when the motor is running at a certain speed or is taking a certain current, the nuts e , must be adjusted until the speed or current is as desired, preventing the lever L from revolving by stops, and then varying W until a balance is obtained, when the stops are taken away. In making the measurement, it may be necessary to allow a little water to run upon the inside of the pulley, to absorb the heat generated by the friction. The wood blocks run best when dry, and a little smoke does no harm to the measurement. Instead of an adjustable weight W , a spring balance is more convenient. This is a very satisfactory method of testing small motors; for large ones, the heat is too great to be readily dissipated unless a special pulley is used which will hold water inside the rim.

The *power* of a motor is the product of the torque and the speed. For, if a force W acts at the end of an arm R fastened to a shaft, in one revolution the distance traversed by the point of application of the force is $2\pi R$, and the work done $2\pi R \times W$. In the case represented by Fig. 7, the work done by the revolving shaft is the same as if a weight W were being continually wound up on a pulley of radius R . If the shaft revolves N times per minute, the work done per minute is $2\pi R W \times N$; or, since RW is the torque, we may write:

$$\text{Power} = 2\pi \times \text{Torque} \times \text{Speed.} \dots\dots\dots (5)$$

Denoting the torque by T , we have the further result:

$$\text{Horse-Power} = \frac{2\pi T N}{33,000} \dots\dots\dots (6)$$

From Equations 5 and 6, it follows that different motors of the same power may have very different properties. They may give a strong torque at low speed, or a light torque at high speed, or may have intermediate values of both, different kinds of work requiring one property or the other. From the discussion on page 3, it follows that the actual force upon the armature wires depends upon their number and on the strength of the field, and the torque will also vary with the diameter of the armature. A strong torque will therefore be obtained by using an armature of large diameter, with many wires revolving in a strong field; but since these are just the conditions for a high E.M.F., such an armature will generate its full counter-E.M.F. at a lower speed than a smaller armature with fewer wires; that is, for a given voltage, the high-torque armature will run at relatively slow speed.

With the aid of Equation 6, it is a simple matter to measure the output of a motor by the brake.

Example. For a certain motor the distance R was 30 inches, the weight W 12.4 pounds, and the speed 1,400 revolutions per minute. What horse-power was developed?

Solution. Since R must be expressed in feet,

$$T = 2.5 \times 12.4 = 31 \text{ pound-feet.}$$

Substituting this value of T in Equation 6, gives:

$$\text{Horse-Power} = \frac{2 \times 3.1416 \times 31 \times 1,400}{33,000} = 8.25. \quad \text{Ans.}$$

EXAMPLE FOR PRACTICE

A 500-volt motor rated at 15 horse-power takes a current of 25 amperes when driving a certain machine. It is then disconnected and fitted with a brake; and a test shows that with $R = 32$ inches,

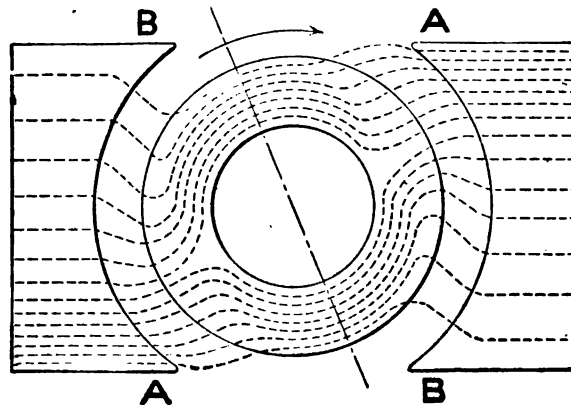


Fig. 8. Armature Reaction in Motor.

and the wing-nuts adjusted until the current is 25 amperes, the speed is 755 revolutions per minute; and $W = 36$ pounds. What is (a) the actual horse-power needed to drive the machine; and (b) the efficiency of the motor?

Ans. 13.8 horse-power, nearly.

82.3 per cent.

Armature Reaction in Motors. In a motor the direction of the armature current, and hence the direction of its magnetic field, are opposite to those in a generator. The resultant field in the motor armature and air-gap will therefore be as shown in Fig. 8. It is evident that the neutral points are shifted backwards, while in a

generator they are shifted forwards; hence for good commutation the brushes must be shifted *against* the rotation, while in the dynamo they are shifted *with* it. Most motors are required to operate without change of brush lead throughout the entire range of load; and this necessitates careful design, to the end that the field-magnets shall entirely overpower the armature reaction and keep the distortion of the field small, so that commutation may be good with the brushes fixed in position, no matter what the load may be. Many motors, particularly railway motors, must in addition run in either direction; and this requires fixing the brushes at the no-load neutral point. Such motors, however, cannot give as good commutation as those in which the brushes may be set backwards—a fact which is shown by the more rapid roughening and wear of the commutator and brushes. Nearly all motors are operated on constant-potential circuits, and carbon brushes are used almost without exception.

General Speed Formula. The factors upon which the speed of a motor depends can be obtained as follows:

The counter-E.M.F. depends upon the strength of the field f , the number of armature conductors z , and the speed of rotation s . Hence we may write $e \propto s f z$, or, in the form of an equation,

$$e = k s f z,$$

in which k is a constant depending on the design of the motor. Substituting this value of e in Equation 1, we have:

$$I = \frac{E - e}{R} = \frac{E - k s f z}{R};$$

and, solving for s ,

$$s = \frac{E - IR}{k f z} \quad \dots \dots \dots (7)$$

As already stated, IR is only from 3 per cent to 5 per cent of E in motors of ordinary size; and if we disregard it, we may write the simple relation:

$$s = \frac{E}{k f z} \quad \dots \dots \dots (8)$$

That is, the speed of a motor is directly proportional to the E.M.F. at the brushes, and inversely proportional to the number of conductors on the armature and the strength of the field.

Other conditions remaining the same, it is plain that an increase in E will increase the speed, for increased E increases the current

and therefore the torque, and the speed must evidently rise as an immediate consequence. But at first sight it is not so clear that the same result will be produced by weakening the field. The reason may be seen, however, by anticipating the result of the calculation on page 20, where it is shown that any reduction of the counter-

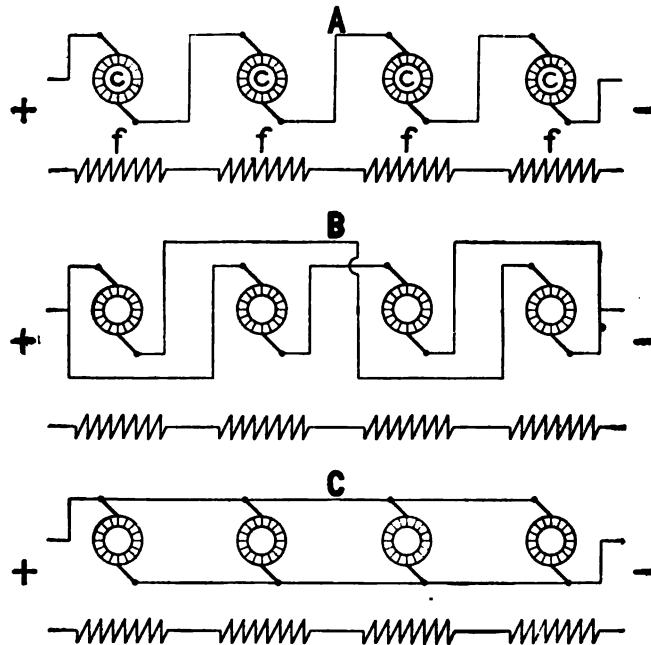
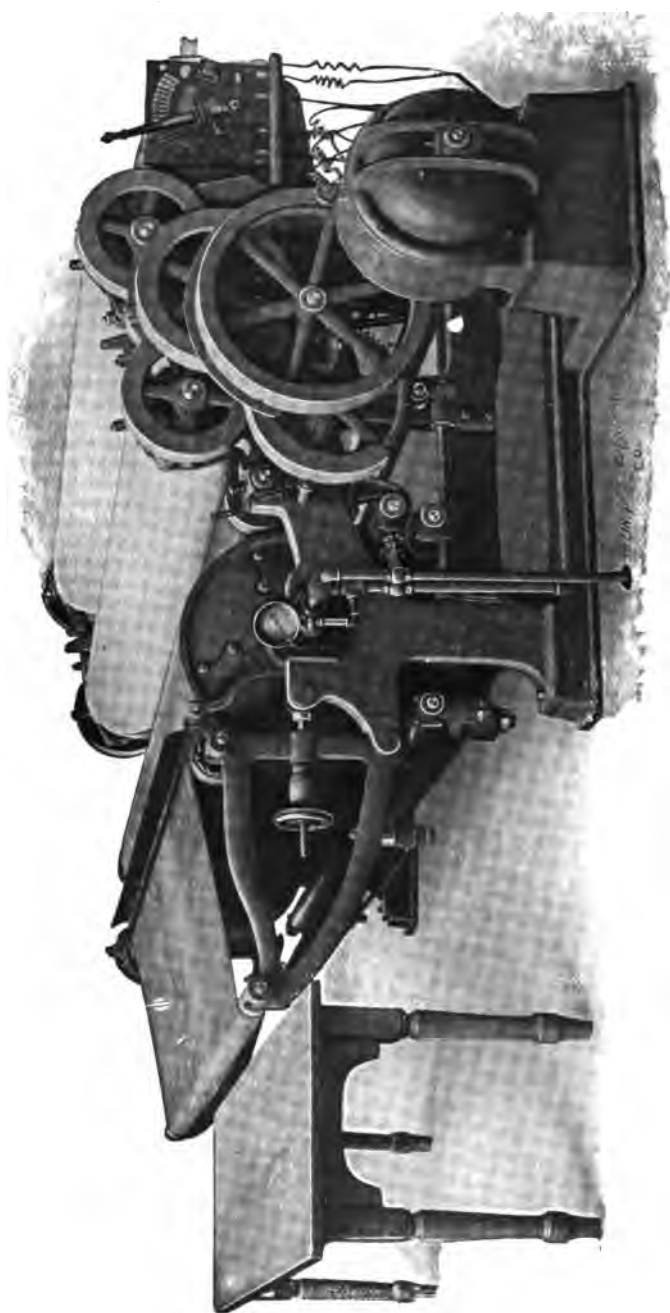


Fig. 9. Series-Parallel Connections of Four Motors.

E.M.F. increases the current in a much greater ratio. In the example there given, reducing the field strength 1 per cent increases the armature current 24 per cent, so that the actual increase in the torque is $\frac{9}{100}$ of 24 per cent (or 23.76 per cent), or practically in proportion to the current. Hence the speed increases, the increased current much more than compensating for the slight diminution in the field strength.

It is often desirable to vary the speed of a motor, and Equation 8 thus gives the three general methods for accomplishing the desired result—namely:

- (1) By varying the *E.M.F.* at the brushes.
- (2) By varying the strength of the field.
- (3) By changing the number of wires on the armature.



FULLY ENCLOSED MOTOR
Driving Hercules Laundry Mangle.
Triumph Electric Company.

Of these, methods 1 and 2 differ in details with different types of motor, and are discussed under each type. Method 3 is not practicable, since for satisfactory operation it would involve several independent windings, each with its own commutator. But where several motors drive one machine, the same result can be obtained by connecting the motor armatures in series or parallel combinations. Thus two motors may have their armatures connected in series or parallel by a suitable switch or controller; in the first case, half the line E is supplied to each armature; in the second case, the full E . With four motors the connections might be made as shown in Fig. 9, giving speeds in the ratio 1:2:4 with the arrangements A , B , and C , respectively, the motor fields f being kept constant. In the actual case, however, two-motor or four-motor combinations are used only in railway work; and four-motor sets are operated with the motors connected in pairs, like a two-motor equipment; in the latter case the additional flexibility of operation does not justify the extra complication introduced by taking the four as separate units. In general, this method of speed regulation is favorable to economical working, for the use of wasteful resistances is much reduced; but it does not warrant the installation of two motors when one will do the work.

CLASSES OF MOTORS

The preceding propositions are true for all classes of direct-current motors; but there are also many special properties depending on the relations that exist between the armature and field, so that it is next necessary to classify motors, like dynamos, with respect to the different methods of exciting the field. We have, accordingly:

1. Magneto motors.
2. Shunt motors.
3. Series motors.
4. Compound motors.

Magneto Motors. Because of the difficulty of making them self-exciting, very small dynamos are built with permanently magnetized fields. With motors, however, there is no such difficulty in obtaining the field, so that the magneto motor is not used, except where rotation in one direction or the other is desired by simply reversing the current without further complication. This is sometimes required in light mechanisms or controlling apparatus.

SHUNT MOTORS

To this class belong most of the motors used for all direct-current power service except railway work. The construction and electrical connections are exactly the same as for shunt dynamos, and any good shunt dynamo will make a correspondingly good motor. Shunt motors are practically always operated on constant-potential circuits, and, except at starting, the electrical connections are as shown in Fig. 10, both armature and field being con-

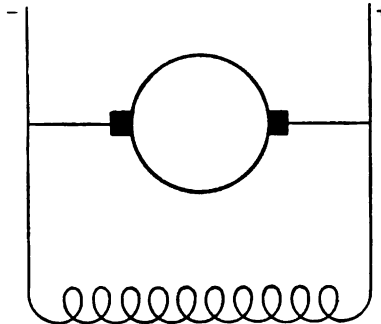


Fig. 10. Connections of Shunt Motor when Running.

nected across the line. Hence the field current and the field strength will be constant, and the torque will vary directly as the current through the armature, the current itself being determined by Equation 1.

The action of the shunt motor may be explained as follows:

Since the counter-E.M.F. varies as the product of the speed, strength of field, and number of armature wires, and the two latter factors are constant in this case, it follows that any change in the speed will cause a proportionate change in the counter-E.M.F. e ; but, since e is nearly equal to E (the line E.M.F.), the current through the armature will change in a much greater ratio, a small decrease in the counter-E.M.F. causing a much greater increase in the current, and hence in the power delivered by the motor. For example, if the counter-E.M.F. of a 125-volt motor is 120 volts at a speed of 1,000 revolutions per minute, and the armature resistance is 0.2 ohm, the current at this speed is:

$$\frac{E - e}{R} = \frac{125 - 120}{0.2} = 25 \text{ amperes.}$$

If an additional load is put upon the armature, it naturally slows down. Suppose it to slow down to 990 revolutions per minute. The counter-E.M.F. will then decrease to $\frac{990}{1,000}$ of 120, or 118.8 volts; and the current will rise to:

$$\frac{125 - 118.8}{0.2} = 31 \text{ amperes.}$$

That is, a decrease of 1 per cent in the speed causes an increase of 24 per cent in the current; and the speed will continue to diminish until the current increases enough to supply sufficient power to prevent further speed reduction—that is, until the increased input equals the increased demand. Similarly, a diminished load which will allow the armature to speed up to 1,100 revolutions per minute will be accompanied by a decrease of 24 per cent in the current. Small variations of speed like this are not readily noticed; and to the casual observer the motor seems to adapt itself with uncanny knowledge to its work, in taking without apparent effort the precise current for every demand. The explanation lies, as we see, in the fact that only a slight change is needed in the delicate balance between E and e to

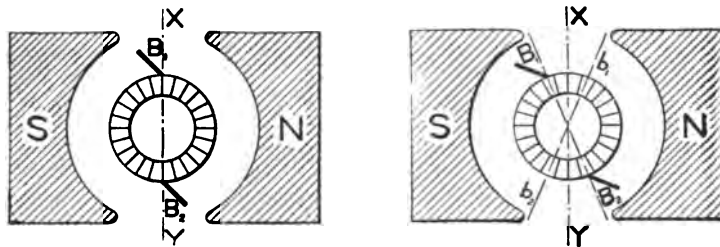


Fig. 11. Demagnetizing Effect of Motor Armature.

accomplish the observed result, by speed variations which are usually too small to notice, unless very sudden. If the load should be removed entirely, there is no tendency for the motor armature to race, for every slight increase in the speed increases e and diminishes the flow of current from the line, thus cutting off the power supply when it is not wanted.

The smaller the value of R , the greater will be the change in I for a given change in e ; in other words, the smaller will be the variations in speed with changes of load. Since e differs from E by IR , the E.M.F. required to send the current through the ohmic resistance of the armature, and in well-designed machines IR is only from 3 per cent to 5 per cent of E , the speed falls off from no load to full load only by this small percentage; and we have in consequence the very valuable ability of the shunt motor to run at practically constant speed, irrespective of the load upon it. The small variations that actually do occur are not, as a rule, of sufficient importance to warrant special devices for their correction.

EXAMPLE FOR PRACTICE]

Calculate the current through the above-mentioned motor when the speed is 1,100 revolutions per minute.

ANS. 18.95 amperes.

Effect of Armature Reaction on Speed. To eliminate sparking, we have seen that it is necessary to shift the brushes of a motor backward, and those of a generator forward. In both cases, there is introduced a demagnetizing belt of conductors, which weakens the field. This is illustrated in Fig. 11, which shows the motor brushes drawn backward from the no-load position. This action creates a demagnetizing belt of conductors lying between B_1 and b_1 , and between B_2 and b_2 . As the motor is loaded, the field is therefore progressively weakened by the increased current through this belt of conductors, and the counter-E.M.F. reduced correspondingly, which tends to increase the speed. Thus, by giving considerable backward lead to the brushes, it is possible to obtain nearly constant speed at all loads. Not all motors are designed to operate with so great a lead as this would often require; but the effect is always present in some degree, to the further advantage of the constant-speed tendency of the shunt motor.

Speed of Shunt Dynamo Used as Motor. If a shunt dynamo is used as a motor on a line of the same voltage, its speed as a motor will be less than when generating the line voltage as a dynamo. To find what the motor speed will be, we may proceed as follows:

To supply I amperes to the line at E volts, E_a , the E.M.F. generated in the armature, must be $E_a = E + IR$, where R is the armature resistance, because some of the E.M.F. generated is expended in sending the current through the armature itself. The E.M.F. generated in the armature of the same machine used as a motor is, from Equation 1:

$$e = E - IR.$$

Since the field strength is the same in the two cases, both being supplied at E volts, the armature E.M.F.'s will be directly proportional to the speed; or,

$$\frac{\text{Motor Speed}}{\text{Dynamo Speed}} = \frac{e}{E_a} = \frac{E - IR}{E + IR} = 1 - \frac{2 IR}{E}, \text{ approximately.} \quad (9)$$

Since $\frac{IR}{E}$ lies ordinarily between 0.03 and 0.05, as we have seen,

it follows that the speed of a given machine as a motor will be generally from 6 per cent to 10 per cent less than its speed as a dynamo. If, however, the field strength is not constant, either because of armature reaction or changes in the field current, the relation, of course, ceases to hold.

EXAMPLE FOR PRACTICE

A certain dynamo is rated at 25 kilowatts at 220 volts and 600 revolutions per minute. Its armature resistance is 0.08 ohm. What is its full-load speed as a motor?

Ans. 550 r.p.m.

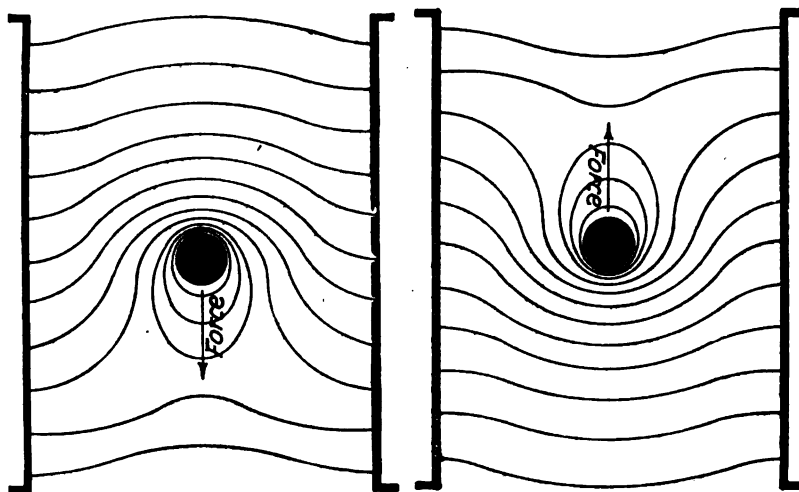


Fig. 12. Force on Dynamo Armature Conductor Moving Upward.

Fig. 13. Force on Motor Armature Conductor Moving Upward.

Direction of Rotation of Shunt Motor. To examine the behavior of a shunt dynamo used as a motor, a modification of Fig. 3 may be used. Fig. 3 gives the general directional relations between the field, current, and force upon an armature conductor; and Fig. 12 represents the case of a wire on a dynamo armature, moving toward the top of the page, the current creating a force on the wire which is against the direction of the motion, so that power is required to keep up the rotation. Now, if the machine is used as a motor driven by current from the same line, the direction of the field remains the same; but the current through the armature is reversed, and the field of Fig. 12 will be changed to that of Fig. 13. The force on the armature wires is reversed, and is now in the direction of the rotation,

instead of against it as in the dynamo; consequently the armature will rotate in the direction of its rotation as a dynamo. The reversal of the current through the armature, and not through the field, is shown in Fig. 14.

This property is of considerable importance when shunt dynamos are operated in parallel. If reduced speed should cause the E.M.F.

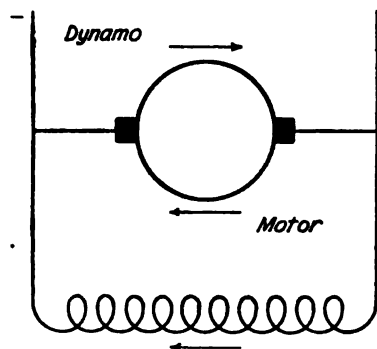


Fig. 14. Direction of Current in Shunt Dynamo and Motor.

of any machine to fall slightly below the line E.M.F., the armature merely continues to revolve in the same direction as a motor, and no harm is done.

To convert a shunt dynamo into a motor, therefore, if the direction of rotation is to remain the same, no change whatever is necessary. A starting rheostat must be added, but the machine itself needs no alteration.

The Starting Resistance. Very small motors are started by simply closing the switch that connects them to the line. No further apparatus is necessary, especially if they are series-wound, as is frequently the case to save the expense of a fine-wire shunt winding. For motors larger than about one-quarter of one horse-power, at full speed, the counter-E.M.F. prevents the current from exceeding safe values; but at starting, e is of course zero; and since R is always very small, the rush of current that would take place on throwing the full line voltage upon the motionless armature would blow out all the fuses, or might damage the armature or even the line itself. Hence it becomes necessary to insert a resistance temporarily in the armature circuit, cutting it out gradually as the speed rises. Such a resistance is called a *starting rheostat* or *starting box*.

The diminution of current through the armature as the speed increases may be easily shown by putting an incandescent lamp of about 50 candle-power in series with the armature of a small motor. Fan motors are usually series-wound; and with such it is enough to put the lamp anywhere in the circuit between the motor and the line. When the switch is closed, the lamp burns brightly for a moment and then grows dim as the armature speeds up, showing that

under these conditions the starting current is much greater than the running current. The resistance of such small motors is high enough to prevent damage to the motor during the two or three seconds required to come to full speed, even though no starting resistance is used.

The starting box itself consists mainly of a resistance divided into small sections and arranged with suitable contacts so that by moving the arm of a switch the sections can be cut out one after another. At full speed, the entire resistance is cut out, and the full line E.M.F. is applied to the armature terminals. The resistance

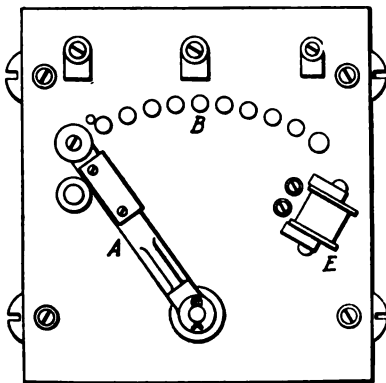


Fig. 15. Face of Starting Box.



Fig. 16. Interior of Starting Box.
Westinghouse Electric & Manufacturing Company, Pittsburgh, Pa.

itself is made of iron wire or ribbon, wound upon asbestos-insulated tubes or strips, or embedded in insulating enamel.

The face of such a rheostat has the general appearance shown in Fig. 15, which shows the movable switch arm *A*, the row of contact studs *B*, and a small magnet *E* whose function will be explained later. The interior of a rheostat is illustrated in Fig. 16. One side and the bottom of the box are shown removed for inspection of the resistance coils or for repairs.

When the motor is of 50 horse-power or over, the sparking that always occurs at the contact-studs soon burns them and causes trouble, and the form of rheostat shown in Fig. 15 is being superseded by a type in which the sections of the resistance are cut out by separate switches. One such form is shown in Fig. 17. The cut represents a multiple-switch starter for a 500-horse-power, 220-volt motor.

The first switch on the left is held closed by an electromagnet through which the field current passes; and the other switches are held by latches. Each switch has upon it a metal plate which prevents closing it until the switch at its left has been closed; and the interlocking mechanism thus obtained prevents a careless operator from closing the switches in the wrong order. When the current is cut off, the switch on the left is opened automatically by a spring, and this

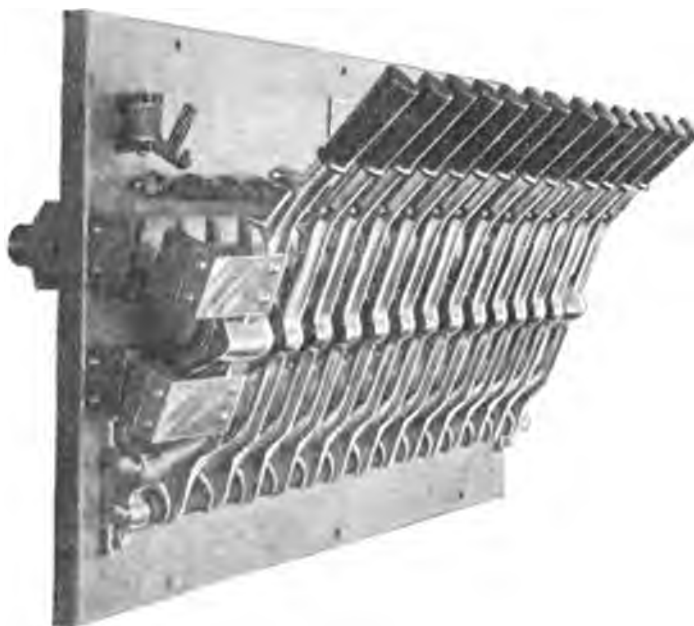


Fig. 17. Front of Multiple Switch Motor Starter, with Automatic Release. Cutler-Hammer Manufacturing Company, Milwaukee, Wis.

frees the switch next to it; this opens in turn; and so on until all have opened, when the apparatus is ready for starting the motor again.

In starting motor-generator sets, rotary converters, and other apparatus where the starting current is only a small fraction of the running current, it is desirable to cut out the entire starting mechanism after full speed is attained. In such cases a simpler starting device is often used, of relatively small capacity and without automatic attachments. One form of such starting device is shown in Fig. 18. The picture shows clearly the way in which the steps of the resistance are cut out as the switch-blade is slowly pushed home. This switch

is placed on the general switchboard of the apparatus, and the resistance mounted separately.

The maximum resistance R of the starting rheostat is determined by the equation $R = \frac{E}{I}$, where I is the current required to

start the motor. Frequently motors must start under load, and the necessary starting current is considerably greater than the normal full-load running current—sometimes two or three times as much. Any good motor will safely endure this overload for the 15 or 30 seconds required to come up to speed; and many starting rheostats are designed to carry for this time a 50 per cent excess over the full-load motor current. But when a greater starting current than this is needed, or when it is desirable to allow the motor a minute or more in which to come up to speed, the ordinary starting rheostat is liable to overheat, and one of larger size must be installed. With a box designed to start the motor under load, the speed will rise rather quickly if the motor is not loaded; but this does no harm if the current is not excessive.

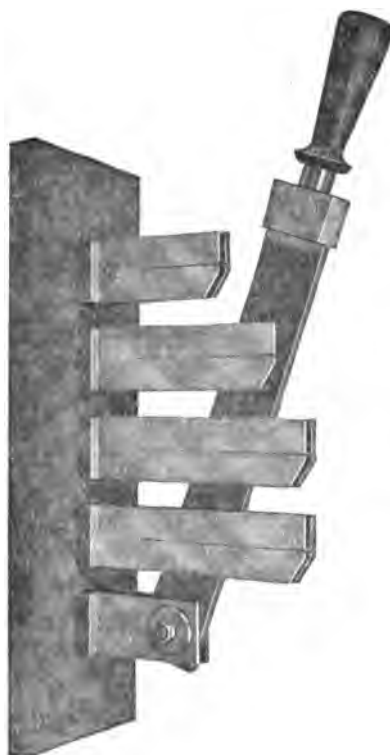


Fig. 18. Multi-Point Switch.
Westinghouse Electric & Manufacturing
Company, Pittsburg, Pa.

Electrical Connections of Shunt Motor. Fig. 19 represents perhaps the simplest method of wiring a shunt motor and starting rheostat on constant-potential mains. From the line, the wires lead through a fuse-block F and a double-pole switch S . If the motor is a large one, a circuit-breaker is better than fuses. On tracing out the connections, it will be seen that when the switch S is closed the current flows through the motor fields. With the rheostat arm a in

the position shown, no current flows through the armature; but on moving the arm to the first contact, the armature circuit is closed through the resistance R , which is gradually cut out as the handle is moved to the left. Opening the main switch cuts off the line current, but leaves the field connected across the armature terminals, as in a dynamo; so that, as the motor comes to rest, the fields die down

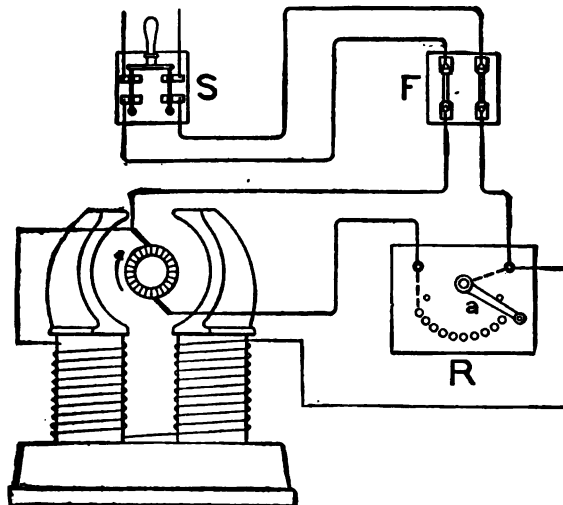


Fig. 19. Wiring Connections of Shunt Motor.

gradually without the destructive flash that would occur if the field circuit were opened suddenly while the magnets are excited. For this reason the field circuit should not be opened first.

When the armature has come nearly to rest, the rheostat arm is restored to the original position, and the motor is ready for starting again.

Automatic Release. The preceding diagram has been drawn to reduce the principle to its lowest terms and to keep the drawing clear; but in practice the simple rheostat shown is seldom used. After the motor is shut down by opening the main switch, the rheostat lever must be moved back by hand, to the starting position; and this is an operating detail that is very easily forgotten. Consequently, when the motor is to be started again, the position of the arm may not be noticed, and damage may be done by closing the switch with no resistance in the armature circuit. Furthermore, the power supply may be cut off and the line may become "dead" while the motor is

running, whereupon the motor stops of itself with the rheostat arm in the running position as before. It is therefore the almost universal custom to install rheostats which are arranged to allow the arm to fly back automatically to the off position whenever the power is shut off from the motor. One method of accomplishing this is to connect the auxiliary or retaining magnet shown in Fig. 15 in series with the

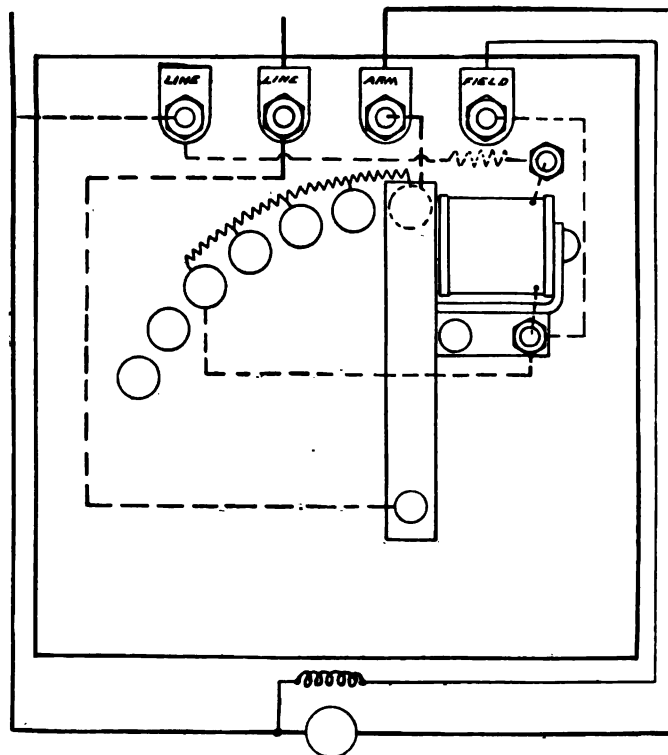


Fig. 20. Connections of Motor-Starting Rheostat with No-Voltage Release.

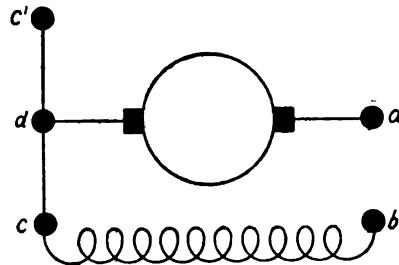
motor fields, the rheostat arm being provided with a spring tending to throw it back into the off position. When in the running position, as shown, the iron arm is held by the attraction of the magnet against the force of the spring; but when the motor loses its field, the magnet loses its power, and the spring carries the arm back into the off position. The retaining magnet is placed in series with the field rather than the armature, because it is thus independent of the load on the machine, and in addition affords protec-

tion in case the field circuit should be broken while running, thus leaving the armature without any counter-E.M.F.

There are other ways of accomplishing the same result. The one shown in Fig. 20 represents a method of connection employed by the General Electric Company. Here, as may be seen by tracing out the connections, the retaining magnet is connected across the armature terminals. When the line circuit is opened, the rheostat arm is held by the current generated in the magnet-coils by the armature E. M. F., until, as the armature slows down, the magnet weakens, and the spring pulls the arm over into the starting position.

Wiring Connections. Figs. 15 and 19 are typical. The ordinary starting rheostat has three terminals, which are usually marked

Line, *Armature*, and *Field* or *Shunt Field*. There are four terminals on the motor (*a*, *b*, *c*, *d*, Fig. 21)—two for the armature and two for the field; but one armature and one field terminal are always at the same potential and may therefore be connected, leaving three separate terminals *c'*, *a*, and *b* on the motor, which



may be called *Line*, *Armature*, and *Field*, respectively.

If the rheostat terminals are marked as above, the wiring of a shunt motor then becomes a simple matter. After putting in the fuses and double-pole switch, first run a wire from one pole of the switch to the rheostat terminal marked *Line*. Run a second wire from the *Armature* terminal of the rheostat to the free terminal *a* of the motor armature, and a third wire from the *Field* terminal of the rheostat to the free terminal *b* of the motor field. This wire, which carries only the field current, may often be made smaller than the others. Finally, run a wire from *c'*, the common terminal of the motor field and armature, back to the other pole of the switch.

A common mistake in wiring consists in interchanging the *Line* and *Armature* wires at the starting box. On the first contact-stud, this puts the field across the brushes and therefore in parallel with the armature, both being in series with the starting resistance. Hence, since most of the line E.M.F. is expended in the resistance, there is

very little across the terminals of the field winding and the armature; and the field is consequently so weak that the motor may not develop sufficient starting torque unless the current is large enough to injure the starting box. This is one of the first places to look for the trouble, if a motor does not start properly when first installed.

There are several methods of arranging the connections inside the starting box itself, as shown in Fig. 22, in which the retaining magnet *E* is drawn outside the box for clearness. It will be noticed that the only difference is in the connection of the field circuit. In the upper diagram, closing the switch establishes the field circuit; while in the lower diagram, no current flows until the rheostat arm is moved to the first stud. In the lower diagram the starting resistance is always in the field circuit; but its resistance is so small compared with that of the field coils that its effect is not noticed. By an auxiliary contact *m*, the resistance is sometimes cut out entirely. The little magnet *E* takes only a few watts, and is without effect on the operation of the motor.

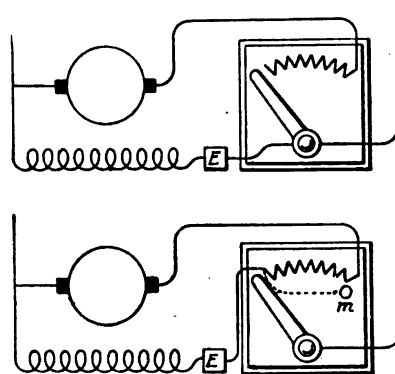


Fig. 22. Starting-Box Connections.

Overload Release. This is a useful addition to the starting box, for the purpose of cutting the motor out of circuit when the armature current becomes excessive, without relying on the fuses or circuit-breaker. It consists of a second electromagnet through which the armature current passes, mounted on the face of the starting box, and provided with a movable armature which hangs down like a hinge below the magnet-poles. When the current exceeds the proper strength, the armature is lifted by the attraction of the magnet and presses against little contact-pins, short-circuiting the release magnet holding the rheostat arm, whereupon the arm at once flies back to the off position.

This device is not intended to be used as a substitute for the fuses, but is adjustable and useful for taking care of overloads not exceeding about 50 per cent. Heavier fuses may then be used, giving

the necessary protection but saving the annoyance of frequently blown fuses. Fig. 23 shows the connections of a rheostat equipped with an overload release of this type.

OPERATION OF MOTOR

To Start the Motor. In starting the motor, the following directions are to be observed:

1. Close the main switch. According to the method of con-

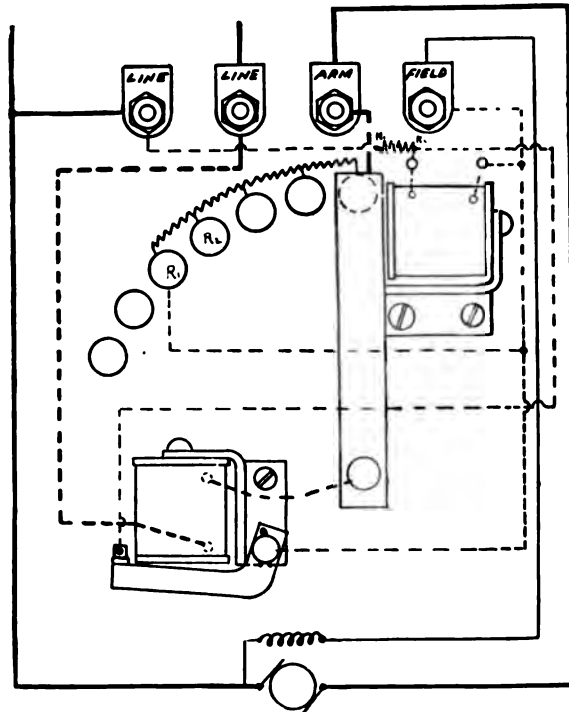


Fig. 23. Connections of Motor-Starting Rheostat with No-Voltage and Overload Release.
General Electric Company, Schenectady, N. Y.

nection, as shown in Fig. 22, this will either establish the current through the field, or will merely bring the line voltage up to the starting box.

2. Move the rheostat lever to the first contact, and hold it there for one or two seconds.

3. Move the lever to the second stud, and hold it there for about one second; and so on, until all the studs have been passed

over and the resistance is short-circuited. The lever should then be firmly held by the retaining magnet. The entire operation should not consume more than 15 to 30 seconds.

If the motor does not start when the lever is on the third stud, open the main switch, and look for the trouble. It may be due to one or another of the following causes:

1. Overload.
2. An open circuit somewhere.
3. A short circuit somewhere.
4. Wrong connections.

No cause of motor trouble is more common than simple overloading. Always at the time of installation, and occasionally thereafter, an ammeter should be connected into the motor circuit, and its reading compared with the rated current of the motor. Motors are designed to do their work with but little attention. They frequently get none at all; belt, commutator, and bearings are neglected; additional machinery is put into the shop and operated from the original motor; and so on—with the inevitable result of overload.

The methods of locating troubles and remedying them, and of caring for dynamo-electric machinery in general, are matters of such importance that their full discussion requires treatment in a separate paper.

To Stop the Motor. Open the main switch. The motor will run for a little time by its own momentum, and the retaining magnet will not allow the rheostat arm to fly back until the armature has slowed down considerably. If the contact-studs are dirty, the lever may not move readily over them; and if it does not fly back sharply, they should be cleaned, and the spring on the lever adjusted if necessary.

Reversing Direction of Rotation. Most motors are now built with radial brushes, and may rotate equally well in either direction. To reverse the rotation, it is necessary to change the direction either of the field or of the armature current, but not of both, since the double reversal would be equivalent to turning Fig. 3 over twice, leaving the force upon the armature, and consequently the rotation, in the same direction as before.

To allow easy connection for rotation in either direction, some motors are provided with separate field and armature terminals, as

shown in Fig. 24. The direction of the armature current can then be reversed by changing the connections as shown.

In motors which are to be reversed while in operation, the armature connections are the ones changed, because this causes less severe

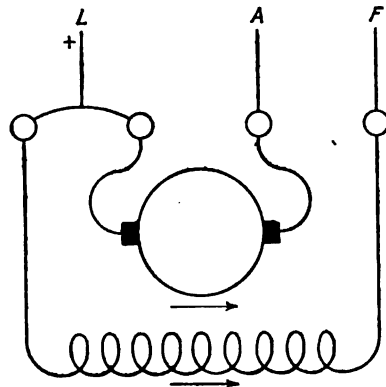


Fig. 24. Connections for Reversing a Motor.

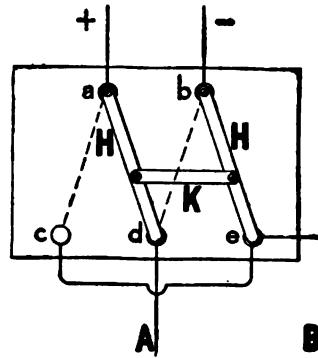


Fig. 25. Reversing Switch.

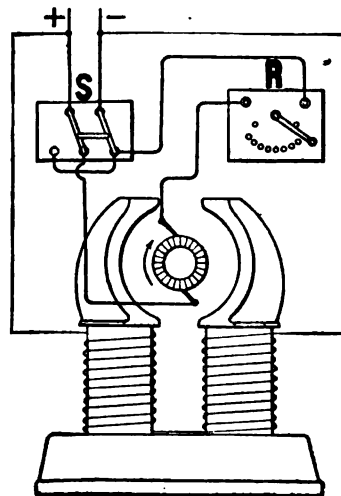


Fig. 26. Connections of Reversing Switch.

strains on the insulation than reversing the highly inductive field circuit. If the motor is merely to be reversed once for all, the brushes should be shifted to the proper lead on the other side of the no-load position; but if it must run in either direction while at work, of course no lead can be given to the brushes, and they must be fixed permanently in the no-load position.



WHITE COMBINED PUNCH AND SHEAR, DRIVEN BY GENERAL ELECTRIC
INDUCTION MOTOR

A motor should never be reversed while running, except for the most necessary reasons, and then not until the full resistance is inserted in the armature circuit. For with the line E.M.F. reversed, the counter-E.M.F. of the armature is for a moment added to that of the line, and the excessive current that flows brings the armature to a stop with a severe jolt that is very likely to cause damage.

Fig. 25 shows one form of reversing switch; and Fig. 26, the manner of its connection into the armature circuit. In Fig. 25, *H* and *H* are brass bars pivoted at *a* and *b*, and connected by a fiber cross-piece *K*. As shown, they are in contact with the studs *d* and *e*. When *K* is moved so as to bring the bars on the studs *c* and *d*, as shown by the dotted lines, it is easy to see that the current will be reversed in the circuit *AB*.

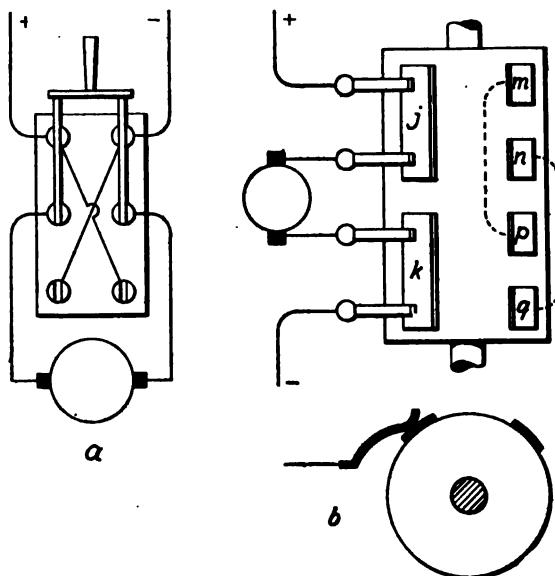


Fig. 27. Reversing Switches.
a—Knife Switch; b—Cylinder Switch.

Fig. 27 shows, at *a*, a simple and satisfactory reversing switch made by cross-connecting the clips of an ordinary double-pole, double-throw knife switch. The line circuit is connected to the clips; the circuit to be reversed is connected to the switch-blades; and simply throwing the switch up or down accomplishes the result.

At *b* in Fig. 27 is shown the principle of cylinder construction which, in a more elaborate form, is much used for speed controllers. In the diagram, an insulating cylinder carries two rows of contact-blocks against which spring contact-fingers press, connected to the various terminals of the motor circuit. When the cylinder is turned to bring the blocks *j* and *k* into contact with the fingers, the current

will flow downwards through the motor armature; and with the blocks *m*, *n*, *p*, and *q* in contact, the current will flow upwards. It is obvious that this arrangement may be extended to execute much more complicated combinations of circuits, by the use of more fingers and more rows of contact-blocks; and in a highly developed form it is widely used for controlling the motors of street-railways.

Automatic Starters. The control of a motor from a distance

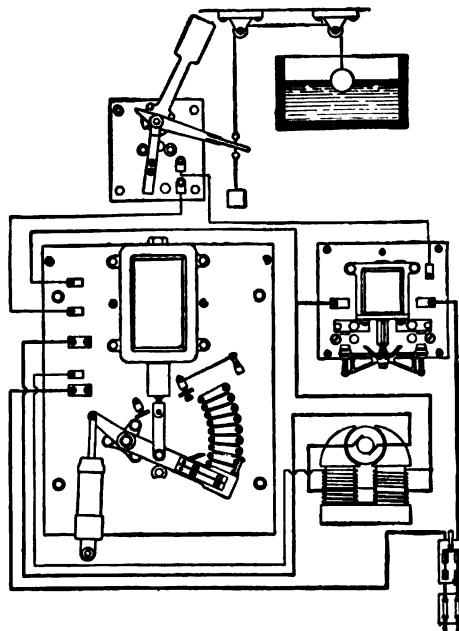


Fig. 28. Self-Starter Used with Motor-Driven Pump.
Cutler-Hammer Mfg. Co., Milwaukee, Wis.

usually involves the necessity of a *self-starting apparatus*, by which all the motions of the starting rheostat are automatically performed on closing the distant control switch.

The movement of the rheostat arm is effected by a solenoid, and the rate of its motion is governed by a dashpot filled with oil. A valve in the dashpot allows the total time of the motion to be varied as required; or thick or thin oil may be used for the same purpose. Perhaps the most common instance of this kind of service is the supply of open tanks with water, and closed reservoirs with compressed air. In the first case, a float switch starts the pump when the water falls below a certain level, and stops it when the tank is full; in the second case, the pressure must be kept within certain limits, and a diaphragm valve makes and breaks the control circuit.

Fig. 28 shows a self-starter operated by a float switch. This switch, when closed, energizes the solenoid of the main switch shown above the motor in the diagram. Closing the main switch also energizes the solenoid on the rheostat arm, and the arm rises, thus starting the motor. At the end of its travel, the arm breaks a contact, and by so doing inserts an incandescent lamp in the circuit of the solenoid, preventing overheating, a small current being enough

to hold the arm in place. The motion of the arm also inserts a lamp resistance in the circuit of the main switch solenoid, as a safety device. For if the main switch is opened, and then closed before the rheostat arm has inserted all the resistance into the motor circuit, the rush of current might blow the fuses; but the lamp is short-circuited only in the off position of the arm; and only under these conditions is the current strong enough to lift the plunger and close the switch.

Reversing Starters. Lathes and other machine tools must often run backwards as well as forwards. Fig. 29 shows a starting apparatus designed to meet this condition. It is in effect a pair of starting rheostats, designed to bring the motor to full speed in either direction. When the handle is in the middle position, the motor is cut out of circuit; and moving the handle to one side or the other starts the motor forward or backward correspondingly.

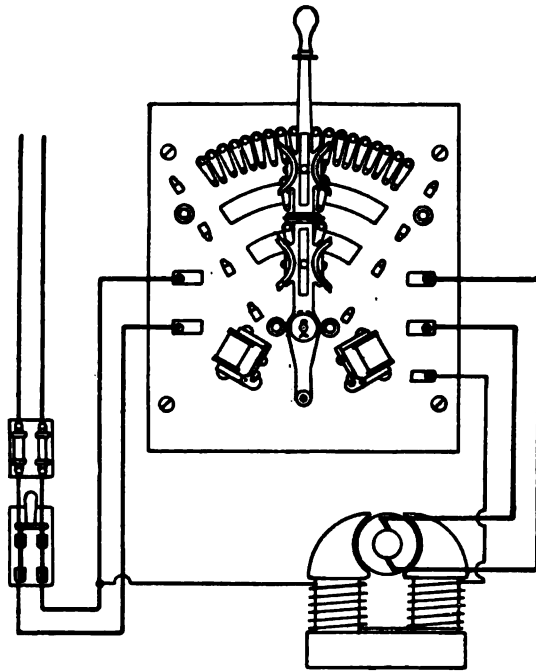


Fig. 29. Full Reverse Motor Starter.
Cutler-Hammer Mfg. Co., Milwaukee, Wis.

SPEED CONTROL OF SHUNT MOTORS

Varying E.M.F. at Brushes. A wide range of speed is easily obtained by simply inserting a suitable resistance in the armature circuit, as indicated by R , Fig. 30, leaving the field circuit FF unchanged. The amount of resistance inserted in order to obtain the desired speed and torque can be calculated in several ways.

Example. A certain 110-volt shunt motor takes 75 amperes at full load, at a speed of 700 revolutions per minute. What resistance must be put in series with the armature to obtain half-speed at two-thirds of the full-load torque?

Solution. In Equation 7 (page 17),

$$s = \frac{E - IR}{k f z},$$

R includes not only the armature resistance, but any other resistance that may be in series with it. At full speed there is no resistance in the armature circuit, except that of the armature itself; and this is negligible in problems like these, so that in this case we may write:

$$s = \frac{E - 0}{k f z} = 700 = \frac{110}{k f z}; \text{ whence } k f z = 0.157.$$

The torque at the new speed will obviously require two-thirds of 75 amperes, or 50 amperes. Therefore, using Equation 7 again,

$$s = \frac{E - IR}{k f z} = 350 = \frac{110 - 50 R}{0.157}; \text{ whence } R = 1.1 \text{ ohms, nearly.}$$

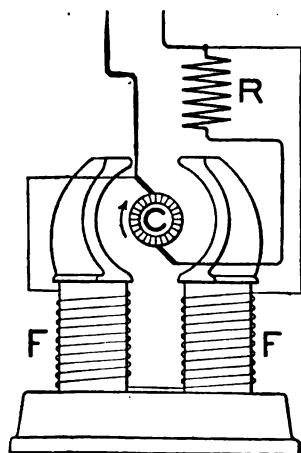


Fig. 80. Speed Control by Resistance in Armature Circuit.

For a more exact solution, the armature resistance should be known; but the above method is quite accurate enough for all ordinary cases.

The above method of speed control has the advantage of simplicity, cheapness, and wide range. It is objectionable, however, when the load is fluctuating, for the E.M.F. at the armature terminals, and hence the speed, depend upon the IR loss in the resistance; and IR of course varies with every change in I . Thus, whenever the load increases, the speed will decrease, and conversely; and this is objectionable in many classes of work. A second objection is that the

voltage taken up in the resistance represents just so much power wasted, the loss in watts being simply I^2R . With a large motor, this loss may be a somewhat expensive matter; with a small one, the simplicity and convenience largely offset the cost of operation.

EXAMPLES FOR PRACTICE

1. The full-load current of a 250-volt motor is 20 amperes, and the speed 800 revolutions per minute. What resistance is required in series with the armature, to give $\frac{3}{4}$ -speed with $\frac{1}{2}$ -full-load torque?

ANS. 6.25 ohms.

2. What is the power loss in the resistance added to the 110-volt motor discussed above? Ans. 2,750 watts.

3. What fraction of the power supplied to the 220-volt motor above discussed is wasted in the added resistance?

Ans. 25 per cent.

It is important to note that for the above purposes the starting rheostat must never be used. The specific heat of the materials of the rheostat is utilized to keep its temperature within safe limits during the brief time required for starting. The box is not large enough to

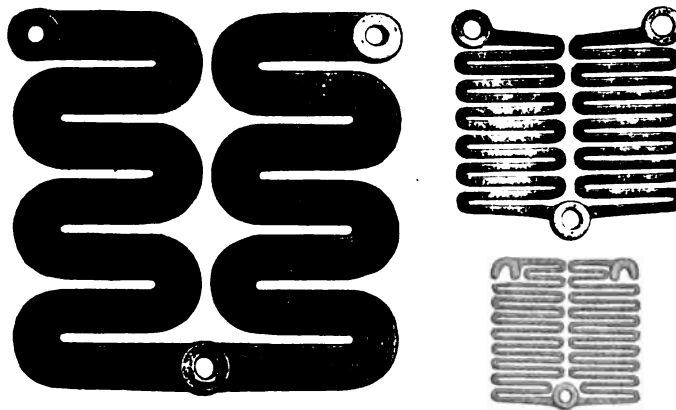


Fig. 31. Standard Grids.
Westinghouse Electric & Manufacturing Company, Pittsburg, Pa.

dissipate much heat, and, if used as a speed controller, would burn out in a very short time. Resistances used to dissipate much energy continuously, must have liberally proportioned surfaces and free ventilation. Small ones are usually made of iron wire, larger ones of iron ribbon, wound on asbestos supports to expose as much surface as possible to the air; very large ones are made of zigzag strips of cast iron, called *grids*. Fig. 31 shows single grids of various sizes. As many elements as needed are assembled in iron frames.

Speed Control by Varying Field. This method is very simple in principle, and wastes but little energy in the controlling resistance. By varying a resistance in series with the field windings of a shunt motor, the field, and hence the speed, are controllable to a certain extent. The advantage of this method of control is in its simplicity, and in the fact that since the field current is small, there is but little energy wasted and little heat to dissipate from the rheostat. Further,

the speed is adjustable by small steps. The disadvantage of the method arises from the fact that the field must not be weakened below the point of satisfactory commutation. This, with an ordinary motor, limits the speed variation to about 25 per cent, or perhaps 30 per cent. If a greater range than this is required, a larger and

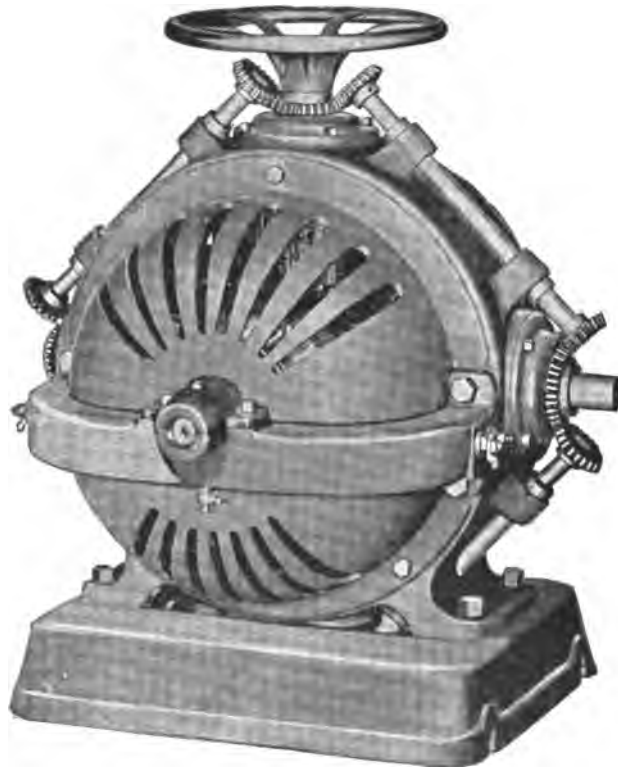


Fig. 32. Variable-Speed Motor.
Stow Manufacturing Co., Binghamton, N. Y.

heavier field-magnet must be provided; for example, for a 2 to 1 variation, a 15-horse-power frame should be used for a 10-horse-power motor, while a 3 to 1 variation requires a 20-horse-power frame for a 10-horse-power motor, with other sizes in proportion. This, of course, means a motor of large size in proportion to its output. The torque diminishes with the weakened field, and this is just compensated by the increased speed, so that the motor runs with practically constant horse-power output. For

still greater speed variations, special constructions are used, which will be described later. Fig. 43 (page 52) shows an adjustable-speed motor giving a 3 to 1 variation in speed by variation of field resistance.

Apart from the extra size of the motor, speed control by this system is very satisfactory where conditions do not warrant the installation of a multiple-voltage system.

Control by Varying Magnetic Reluctance. If the reluctance of the magnetic circuit is varied, the field strength will vary though

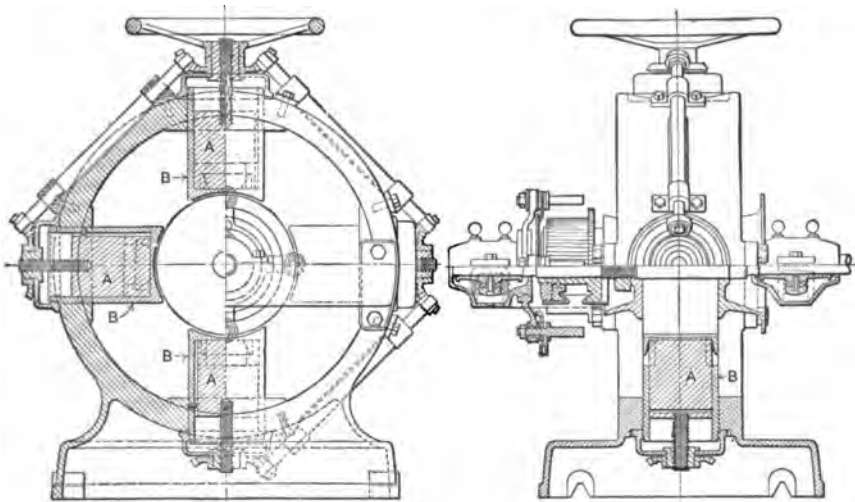


Fig. 32A. Sectional Views of Variable-Speed Motor Shown in Fig. 32.

the field current is kept constant. Advantage of this is taken in the motor illustrated in Fig. 32. In this machine the field cores and poles are hollow and provided with iron plungers, which can be moved toward the armature or away from it by a hand-wheel operating suitable gearing. The advantage of this construction is that, when the plungers are withdrawn, the magnetic flux is obliged to enter the armature through the edges of the pole-pieces; and hence, even with the weakest total field, the actual distribution is always such as to give proper commutation. Moreover, the armature reaction is reduced with weak fields, because iron is removed from the path of the cross-flux, and this also assists commutation. A 3 to 1 speed variation is obtained.

Control by Varying Line E.M.F. This will be discussed later, under the heading *Multi-Voltage Systems*.

Combination Methods. It is evident that the preceding methods of speed control are largely independent of one another, and may therefore be used in combination, giving a wide range of speed; and several combinations are discussed in the following pages. They are applicable to shunt and series motors alike. When a number of running speeds forward and backward are required, as in hoisting machinery and machine tools, and the stops and starts are frequent, as in elevator service, the controlling apparatus must be of the most substantial construction, and is often very elaborate.

SERIES MOTORS

As with series dynamos, the armature and field windings of these machines are in series, and the same current therefore passes through both. They are always used upon electric railways, and in general for operating hoisting and mill machinery, where a strong starting torque is required without the necessity of constant speed. Like shunt motors, they are practically always operated on constant-potential circuits.

Direction of Rotation. In considering the direction of rotation of a shunt dynamo used as a motor (page 23), it was noted that the field and the direction of rotation remain unchanged when the armature current reverses its direction, and the dynamo becomes a motor; but in the case of a series dynamo used under like conditions, the reversal of the current reverses the field as well, and hence the armature tends to rotate in the opposite direction. If, therefore, a series dynamo were feeding a constant-potential circuit, and its E.M.F. fell below that of the line for any reason, its rotation would be reversed and the machine would be injured.

A series motor will run in the same direction, no matter which direction the current takes through it; for reversing the armature current reverses the field as well, and hence leaves the rotation unchanged. To reverse the rotation, it is necessary to reverse the relation of the armature and field currents, and this is usually done by interchanging the armature terminals.

Speed and Torque Curves. When a series motor running at a given speed on constant-potential mains has an additional load put

upon it, the armature slows down, the counter-E.M.F. decreases, and more current flows from the line. But since this current passes through the field-coils, the field strength will increase, and this will further reduce the speed, while the torque will increase enough to take care of the increased load. Throwing off the load will allow the armature to speed up, and this will increase the counter-E.M.F., reducing the current, which in turn reduces the field strength and still further increases the speed, until the power delivered and the losses together

equal the power taken from the line. Hence the series motor has a different speed for every load. If the strength of the field were proportional to the current, the speed curve would be a straight line; but as the current increases, the magnets are more nearly saturated, and the speed decreases less rapidly toward full load.

The speed curve takes, in general, the form shown in Fig. 33, which is from a 50-horse-power railway motor. By having so many turns of wire on the field-magnets that they are well saturated with only a part of the full-load current, the speed variations in the neighborhood of full load are much reduced.

A valuable property of the series motor is the increase of torque in a greater ratio than the increase of current, due to the strengthening of the field at the same time. This is shown by the curve marked "Tractive Effort" in Fig. 33; for a shunt motor, this curve would be a straight line. Hence the torque of the series motor is large when starting under load, and this makes it especially valuable for railway and other service where the starting duty is severe.

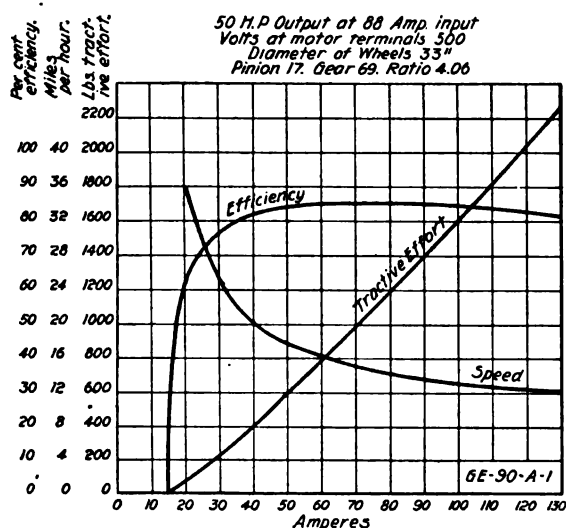


Fig. 33. Speed, Torque, and Efficiency Curves of a Railway Motor.

When the load is removed entirely from a series motor, the diminution of the current, and consequent weakening of the field, are likely to cause excessive and often dangerous speeds, so that it is necessary to provide some safety device for cutting off the current at high speeds, unless the conditions are such that the motor cannot be wholly freed from its load, as in the case of street-cars. Very small motors, such as fan motors, are series-wound; but their normal run-

ning current is so small that they cannot take enough power from the line to injure themselves, even when running free.

Starting Rheostat. The same general principles apply to starting both shunt and series motors; but since there is only one circuit in the series motor, the wiring is simpler. The connections are as in Fig. 34, in which, however, the switch and fuses are not shown. The resistance of the field windings is always in circuit; and this, together with its highly inductive character, helps to cut down the rush of current at starting. The little magnet *E* of the automatic release (Fig. 22) is connected through a resistance across the motor terminals.

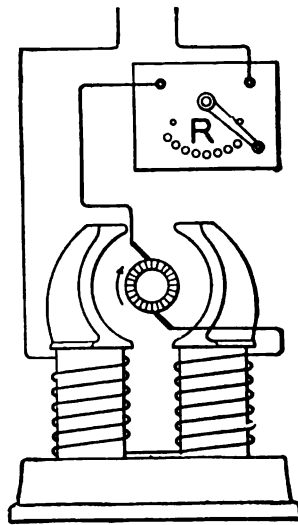


Fig. 34. Wiring Connections of a Series Motor.

SPEED CONTROL OF SERIES MOTORS

Varying the E.M.F. at Armature Terminals. As in the case of shunt motors, all three methods of speed control are practicable, and may be used separately or in combination. With a single motor, varying the E.M.F. at the armature is most easily accomplished by a resistance in series with the motor. The connections are as in Fig. 34, where *R* may represent either a starting rheostat or a speed-controlling resistance, though of course neither piece of apparatus can be used for the purposes of the other unless specially constructed. Controlling the speed by varying the strength of the field is accomplished either by shunting the field windings so that part of the current is diverted through the shunt, or, in some cases, by short-circuiting a part of the field winding, thus reducing the effective

number of turns in the coils. Motors have also been used in which the field-coils were connected in various series-parallel combinations.

Railway Motors. The most important application of the series motor is on the electric railway, the equipment being generally two motors per car. The starting rheostat is specially designed to serve as a speed-regulating resistance as well, and the various armature and field combinations are made by a controller, built like an elabor-

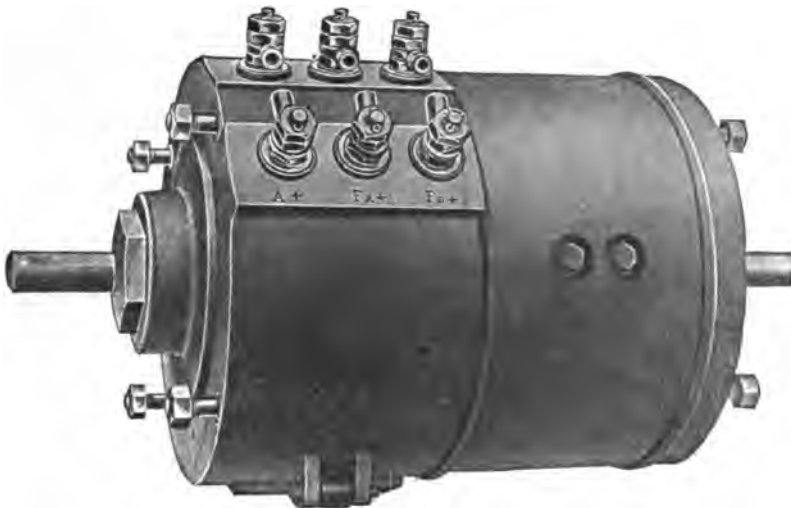


Fig. 35. Vehicle Motor.
Westinghouse Electric & Manufacturing Company, Pittsburg, Pa.

ated form of that shown at *b* in Fig. 27. At starting, the controller connects both motors and a resistance in series, and the resistance is gradually cut out, leaving the motors in series across the line, each receiving one-half of the line voltage and hence running at half-speed. The next position of the controller handle shunts the field or short-circuits a part of the field winding, giving an increase in speed. Further movement of the handle removes the shunt, and connects the motors in parallel, but with a resistance in series with the pair. This is again gradually cut out until each motor receives the full line voltage across its terminals. Finally, the fields are again shunted, and the car runs at its highest speed.

There are slight variations from this program, depending somewhat on the service the motors are called upon to perform. But

these details of the subject of railway working are given special discussion in a separate paper.

Automobile Motors. These are series-wound, usually for operation at 40 to 80 volts, requiring 20 to 40 cells of battery respectively. A ball-bearing vehicle motor is shown in Fig. 35. The requirements for such motors are slow speed, light weight, high torque, complete mechanical protection, liberal overload capacity, and as good an efficiency as can be secured consistently with the above requirements. When two motors are used on the same vehicle, the controller may first connect the motors in series, and the halves of the battery in parallel, other changes following until the motors are in parallel across the full battery voltage, with weakened fields. No rheostat is necessary, as the voltages are low, and the total power delivered usually small.

COMPOUND MOTORS

A reversed compound dynamo becomes a differential motor. Fig. 36 represents a compound dynamo *D* supplying current to a similar machine *M* used as a motor.

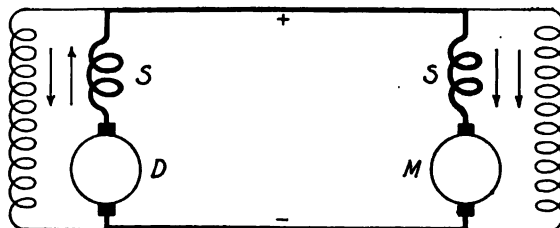


Fig. 36. Compound Dynamo Driving Compound Motor.

It is clear that the current through the series coil of the motor is reversed; and therefore opposes the magnetizing effect of the shunt current, so that the field is weaker than if the shunt were used alone. Furthermore, the motor field is progressively weakened as the armature current increases, and this tends to increase the speed; while the speed of a plain shunt motor under like conditions would decrease. Hence, by suitably designing the series winding, it is possible to obtain a motor whose speed throughout its whole range of load varies very little. This advantage was early recognized; but at the time the speed of ordinary shunt motors was sufficiently constant for most purposes, and the *differential compound motor* made little headway. For some purposes, however, particularly in the operation of textile machinery, it is very necessary to have the speed as uniform as it can be made; and the differential

motor, after a period of comparative retirement, has now a wide field of usefulness.

If the current through the field is reversed, so that it assists the shunt winding instead of opposing it, the machine is called a *cumulative compound motor*, and partakes to a certain extent of the properties of both the shunt and series types, the shunt predominating. These machines are used for elevator and other service where a powerful starting torque is required, together with the general characteristics of the shunt motor. Sometimes the series field is cut out after the armature attains full speed, in which case the strong starting torque of the series motor is combined with the constant-speed property of the shunt motor.

A compound dynamo with a very strong series field will not usually run safely as a differential motor, for an overload might reduce the field so much that with the weakened torque the armature might stop entirely.

Variable-Speed Compound Motors. The success attending the use of the *commutating pole* in generators, has led to the adoption of the same principle for motors designed for wide ranges of speed. The commutating pole is a small additional pole, placed midway between adjacent field-poles, and wound with a few turns of the series winding. Its function is to provide the necessary commutating field for the coil under the brushes, independently of the field of the main poles.

Thus satisfactory commutation not only can be obtained with the brushes in a fixed position, but practically is equally good at all loads, since the strength of the pole, and hence of the commutating field, is proportional to the armature current, and this is exactly what is wanted for good commutation. Applied to motors—since commutation is practically independent of the main field—the use of the commutating pole allows the main field to be weakened much more than with the ordinary construction, and hence a much wider range of speeds is obtainable without sparking. Fig. 37 shows a motor of this type giving a speed range of 4 to 1, entirely by field control.



Fig. 37. Interpole Motor.
Electro-Dynamic Company, Bayonne, N. J.

MULTI-VOLTAGE SYSTEMS

When a generator is to supply only one motor, the line E.M.F. can be varied at pleasure by varying the generator E.M.F., having the generator field rheostat at the motor. This method gives any

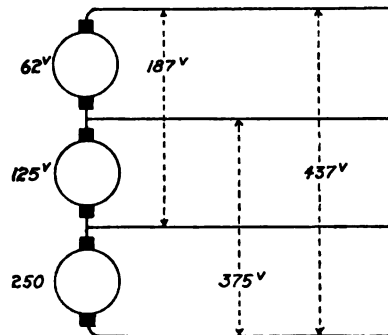


Fig. 38. H. Ward Leonard Multi-Voltage System, 1892.

desired motor speed within a very wide range, but is obviously limited to a few special cases. The so-called *teaser* systems are in effect modifications of this principle; the E.M.F. of small motor-driven generators is added to that of the main line or subtracted from it. This particular modification of the variable line-voltage principle is useful for operating large printing presses or other

machinery which must run very slowly at times under absolute control, as well as at various operating speeds.

The electric automobile affords an example of speed-control by varying line voltage. The batteries of the vehicle are in two sets, which are connected in parallel at starting, and then shifted to series connection at the higher speeds.

The familiar Edison three-wire system affords another illustration. In this case the fields of a 220-volt motor would be supplied from the outside wires, and the armature at either 110 or 220 volts, giving two speeds without the use of resistances.

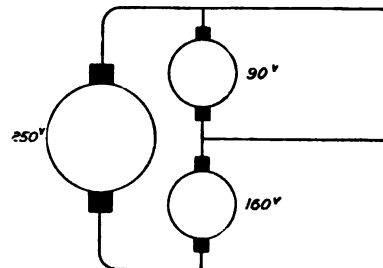


Fig. 39. Connections of Balancer Set.

By making the two sides of the system unequal in voltage, three voltages are obtained. In such a case, the lighting system of the shop, the cranes, and constant-speed motors are operated on the outside wires. A system of this kind was first brought out by Mr. H. Ward Leonard in 1892, using three generators in series and a four-wire system, obtaining the six voltages shown in Fig. 38.

The Bullock Electric Company employs a three-wire system

with 90 and 160 volts, and a four-wire system with 60, 80, and 110 volts, with outside voltages of 250 in both cases. The Crocker-Wheeler Company use a four-wire system with 40, 120, and 80 volts, giving 240 volts on the outside wires. Whatever voltages may be used, it is well to have at least one of the voltages *standard*—that is, 110 to 125 volts, or 220 to 250 volts, because these are standard voltages for lamps and motors.

In practice it is found that the intermediate wires carry only a small proportion of the total load, usually not over 10 per cent. This has led to the use of a single large generator and *balancers*, which are

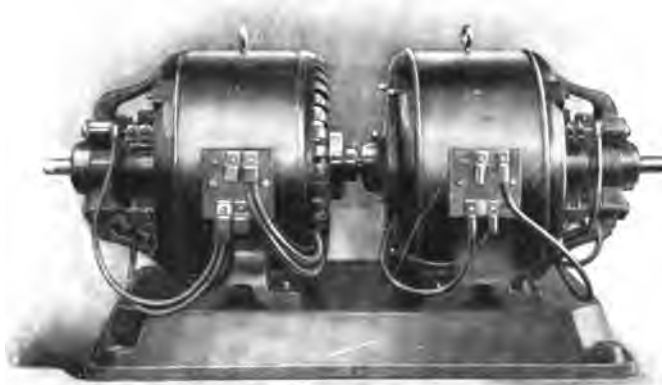


Fig. 40. Three-Wire Balancers for Bullock Multiple-Voltage System. Allis-Chalmers Company, Milwaukee, Wis.

simply smaller shunt or compound dynamos with their armatures coupled together and electrically connected in series across the outside wires. The general arrangement is shown in Fig. 39, and Fig. 40 illustrates a Bullock three-wire balancer set.

The action of the balancer is complex, and a full explanation is not desirable here. In general terms, however, it may be stated that when there is no current in the middle wire of a three-wire system the current through the balancer armatures is only enough to supply the running losses; but when current is drawn from either side of the system, the balancer on the other side will act as a motor, driving its companion as a generator to help furnish the required

power. This is illustrated in Fig. 41, where one outer wire carries 100 amperes, the middle wire 20 amperes, and the other outer wire 80 amperes. If the balancers are equal, and there are no losses, the 20 amperes divide equally between the armatures, 10 amperes flowing downward through one as a motor to the negative main, the armature then acting as a motor driving the other machine as a generator and helping it to force the remaining 10 amperes up into the positive main again. Supposing the voltage of the main generator to be

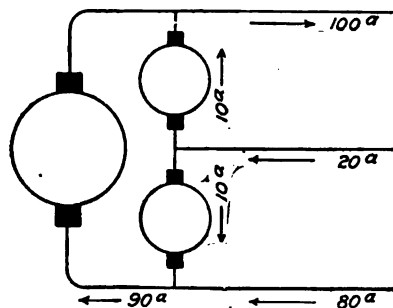


Fig. 41. Current through Balancer Set.

200 volts, its output would be 90 amperes at 200 volts, or 18,000 watts. The load on the line is 80 amperes at 200 volts, and 20 amperes at 100 volts = 18,000 watts, as before.

Of course there are always losses in the balancer armatures, so that in the arrangement shown the current through the armature acting as a motor is always

greater than the current through the armature acting as a dynamo.

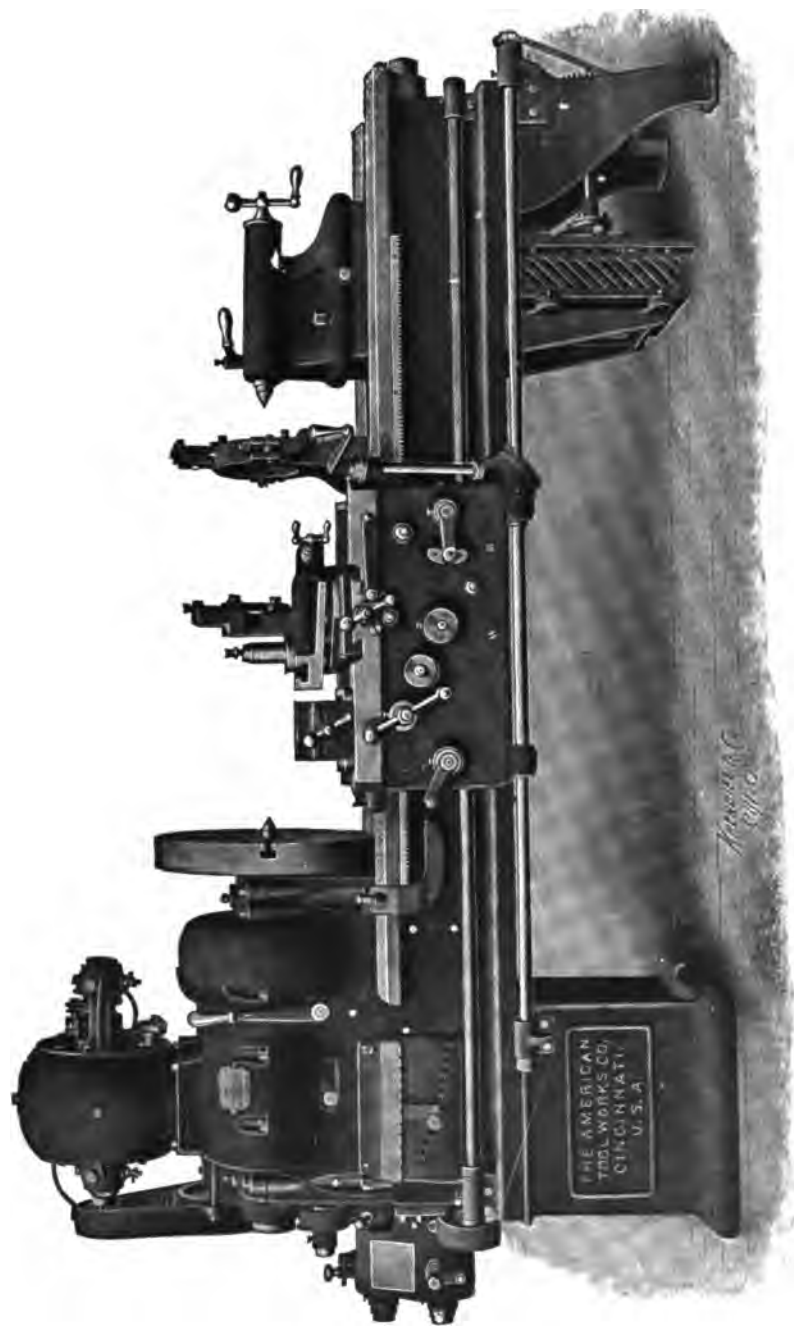
EXAMPLE FOR PRACTICE

If 13 amperes, instead of 10, flow through the balancer motor armature in the above example, what is the output of the main generator, and what power is delivered to the line?

Ans. 18,600 watts from the generator.
18,000 watts on the line.

This would represent 600 watts loss in the balancers, which is, however, much less than would be required to operate the second generator of an ordinary three-wire system.

The size of the balancers is determined by the maximum unbalanced load. On a three-wire system it should be large enough to operate the largest individual motor running alone on either voltage. For example, suppose we have a three-wire, 125- to 250-volt system. If a motor connected to it can develop 50 horse-power at the full voltage 250, it can develop 25 horse-power when operated on one side at 125 volts. This will require two balancers of $12\frac{1}{2}$ horse-power each, since there are two machines to take care of the unbalanced current. In other words, the balancers should have 25 per



MOTOR-DRIVEN AMERICAN ENGINE LATHE.

cent of the capacity of the largest motor, rated at its highest voltage; and this, of course, means that the balancers may be relatively small machines.

Motors operated on this system have their fields excited from some one of the circuits, usually the one of highest voltage. The arma-

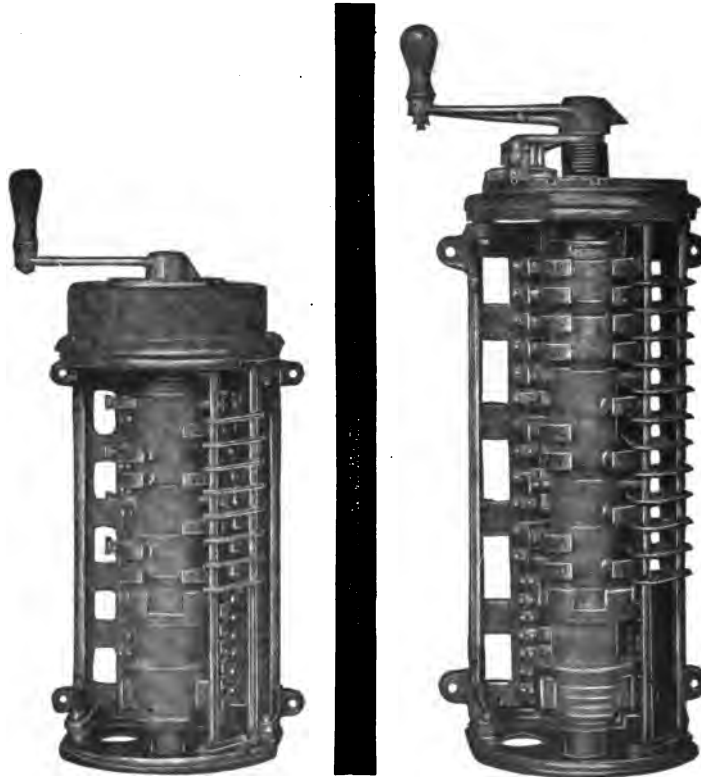


Fig. 42. Controllers Used with Bullock Multiple-Voltage System.
Allis-Chalmers Company, Milwaukee, Wis.

tures are connected to either line voltage as desired, and resistances are introduced to prevent too sudden changes of current at the transition points; additional speed variations are provided by weakening the motor fields. All these connections are made upon controllers of the cylindrical type, of which Fig. 42 is a good example. It represents 20-horse-power and 40-horse-power Bullock controllers without their covers; the larger size gives 12 running speeds forward, and 9 reverse.

MECHANICAL POINTS OF MOTOR DESIGN

Motors need ample protection for the commutator and brush gear. This protection is well shown in the adjustable-speed motor illustrated in Fig. 43. This type of motor is also designed to run with the shaft vertical, in which case the lower bearing runs submerged in oil, and the upper bearing is made of anti-friction metal, running without attention. Motor end-frames or *bells* should be made so that they can be turned through 90° or 180° , to enable the



Fig. 43. Adjustable-Speed Motor.
Crocker-Wheeler Company, Ampere, N. J.

machine to work with the oil wells in the proper position when mounted on a wall or ceiling. If the motor must work in a very dusty or dirty place, the ends may be protected with wire gauze covers, or even tightly enclosed with solid plates.

In such cases,

however, the machine has much more difficulty in dissipating heat; and for the same rise of temperature, the rating of an *enclosed* (and therefore unventilated) motor is not usually more than about half as much as if it were well ventilated. Fig. 44 shows one form of an enclosed motor. Sometimes the frames of enclosed motors are cast with projecting external ribs, to increase the cooling surface.

To obtain very low speeds without using a motor of disproportionately large size for its output, *back-gearing* is often used. Figs 45 and 46 give two views of a back-geared motor. To diminish wear and noise, such gears are often enclosed in cases and run in grease, like the gears of a railway motor.

Motors of large output—which, as a rule, are installed in more favorable surroundings and receive more careful handling than small motors driving individual machines—do not need special mechanical design. They are therefore built along the line of generators; and to a great extent the same parts are used for both.

ELECTRICAL POINTS OF MOTOR DESIGN

Since the motor is electrically identical with the dynamo, it is necessary merely to design a dynamo which will deliver the rated current at the given speed and the *counter-E.M.F.* of the motor. A single illus-



Fig. 44. Enclosed Type R Motor.
Westinghouse Electric & Manufacturing Company,
Pittsburg, Pa.



Fig. 45.



Fig. 46.

Two Views of Type R Motor with Back-Gears.
Westinghouse Electric & Manufacturing Company, Pittsburg, Pa.

tration will suffice. Suppose it is desired to design a 230-volt motor to deliver 10 horse-power at a speed of 825 revolutions per minute. The efficiency of such a machine should be about 85 per cent; so that the current required would be:

$$\frac{7,460}{0.85} \text{ watts} \div 230 \text{ volts} = 38.1 \text{ amperes.}$$

To allow for any error in estimating the assumed efficiency, let us say, in round numbers, that a current of 40 amperes would be required. The resistance of the armature of a machine of this size and voltage will be about 0.3 ohm. Then, from the fundamental motor equation, the counter-E.M.F. can be calculated:

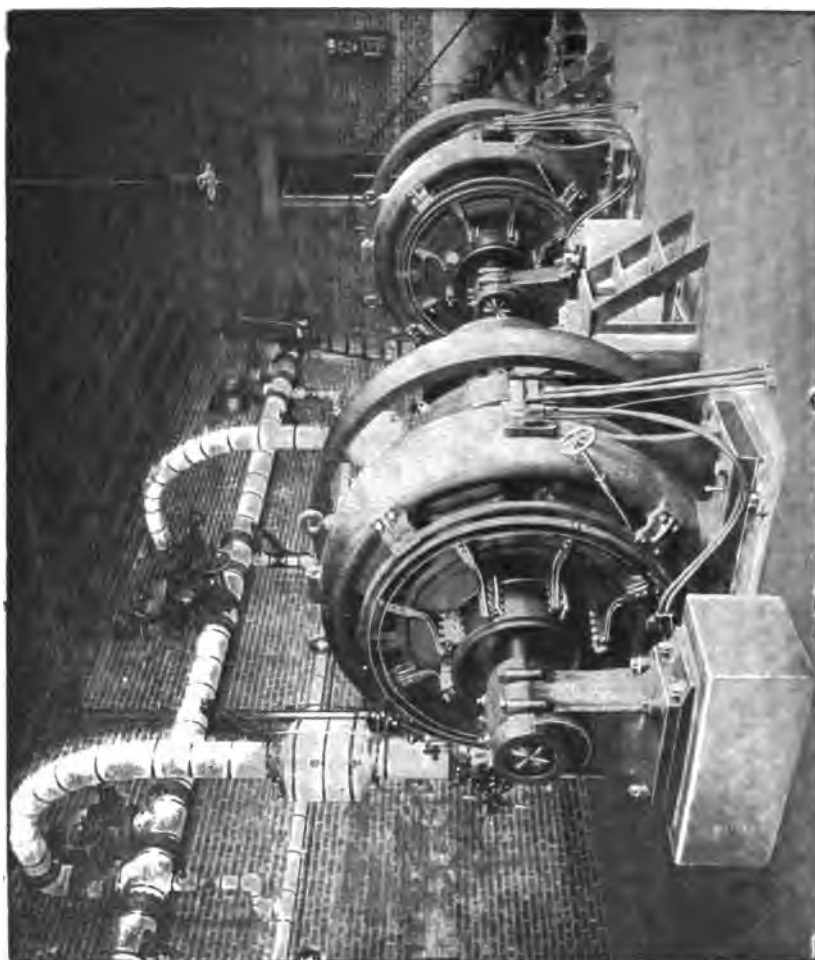
$$I = \frac{E - e}{R} = 40 = \frac{230 - e}{0.3};$$

whence,

$$e = 218 \text{ volts.}$$

That is, a dynamo should be designed whose output at 825 revolutions per minute will be 40 amperes at 218 volts, and whose armature resistance is 0.3 ohm. Its field windings should be calculated for excitation at 230 volts.

For supplementary reading on the subject of the Electric Motor, the reader is referred to the following works: *Dynamo-Electric Machinery*, by F. B. Crocker, and *Electric Railways*, by J. R. Cravath (published by the American School of Correspondence, Chicago, Ill.); *Electric Motors*, by Henry M. Hobart (published by Whittaker & Co., London and New York, 1904); and a series of articles entitled "Direct-Current Motors: Their Action and Control," by F. B. Crocker and M. Arendt, published in the *Electrical World* in 1907 and 1908.



DIRECT-CONNECTED GENERATORS
Operating the Largest Woodworking Plant in the United States.
Triumph Electric Company.

MANAGEMENT OF DYNAMO- ELECTRIC MACHINERY.

The object of this instruction paper is to set forth the most important features which must be considered in the actual handling and operation of electric generators and motors. The principles and general construction of direct-current (D. C.) and alternating-current (A. C.) generators and motors, are treated elsewhere.

The subject may be divided into three parts as follows:

- A. The Selection, Erection, Connection, and Operation.
- B. The Inspection and Testing.
- C. The Troubles or "Diseases" and Remedies.

SELECTION OF A MACHINE.

The voltage, capacity, and type of machine are dependent upon the system to which it is to be connected, and the purpose for which it is to be utilized, but there are certain general features which should be considered in every case.

Construction. This should be of the most solid character and guaranteed first-class in every respect, including materials and workmanship.

Finish. A good finish is desirable, since it is likely to cause the attendant to take greater care of the equipment.

Simplicity. The machine should be as simple as possible in all its parts; peculiar or complicated features should be avoided, unless absolutely essential for the operation of the system.

Attention. The amount of attention required by the machine should be small. The number of screws or nuts should be reduced to a minimum, and they ought always to be provided with some locking device to prevent them from becoming loose. The brushes should be capable of being easily adjusted and self-feeding, so that they may "follow" or make up for any trifling eccentricity of the commutator. The bearings should be self-oiling, and in the smaller sizes self-aligning.

Handling. An eye-bolt or other means by which the machine can be easily lifted and moved is desirable. It ought to be possible to take out the armature conveniently by removing one of the

4 MANAGEMENT OF DYNAMO-ELECTRIC MACHINERY

bearings, or the tops of the field magnet, frame and bearings, or by moving the halves sideways if the frame is split vertically. The armature and field windings should be so designed and mounted that their removal for repairs is an easy matter.

Interchangeability. The machine selected should preferably be one of a regular and standard type, so that extra parts can be obtained without needless delay.

Regulation. Some form of regulating device should be provided by means of which the E. M. F. or current of a generator, or the speed, and in some cases the direction of rotation of a motor, can be readily and accurately controlled.

Form. The machine should be symmetrical, well-proportioned, compact and solid in form. The large and heavy portions should be placed as low as possible, to give greater stability.

Weight. It is a mistake to select a very light machine when it is for stationary use, since weight increases its strength, stability, and durability.

Capacity. This should be ample for the work to be done; in fact it is advisable to allow a margin for increase. The machine should be provided with the maker's name-plate, specifying the rated current, voltage, speed and capacity. The manufacturer should also guarantee the following: That the machine does not heat up in any part of its windings, to more than 50° C, after a run of six hours' duration, under rated load conditions;* also that it is able to carry a 25 per cent overload for two hours, and momentary overloads of 50 per cent, without excessive heating or sparking.

Cost. It is usually an error to select a generator or motor simply because it is cheap, since both the materials and workmanship required for the construction of a high-grade electrical machine are costly.

MECHANICAL CONDITIONS.

Location. The place chosen for the machine should be *dry, free from dust or grit, light, and well ventilated*. It must also be arranged so that there is room enough for the removal of the armature without shifting or turning the machine.

Foundations. It is of great importance to have the machine

*NOTE. By resistance measurements.

firmly placed upon a good and solid foundation; otherwise, no matter how well constructed and managed, the vibrations occurring on a poor foundation will produce sparking at the brushes, and its accompanying troubles.

It is also necessary, if the machine is belt-driven, to mount it upon rails or a sliding bed-plate provided with holding-down bolts and tightening screws for aligning and adjusting the belt while the machine is in operation. (See Fig. 1). The machinery foundations consist of a mass of stone, masonry, brickwork, or concrete, upon which the machinery is placed and usually held firmly in place by bolts passing entirely through the mass. These bolts are built into the foundations, the proper position for them being determined by a wooden template suspended above the foundation, as shown in Fig. 2. The bolts are preferably surrounded by iron

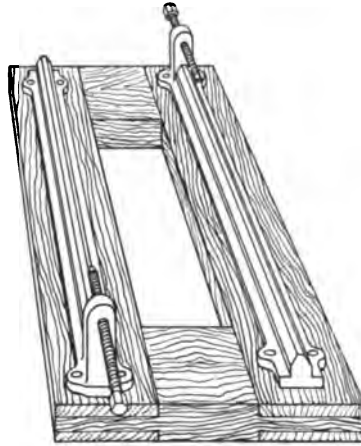


Fig. 1.

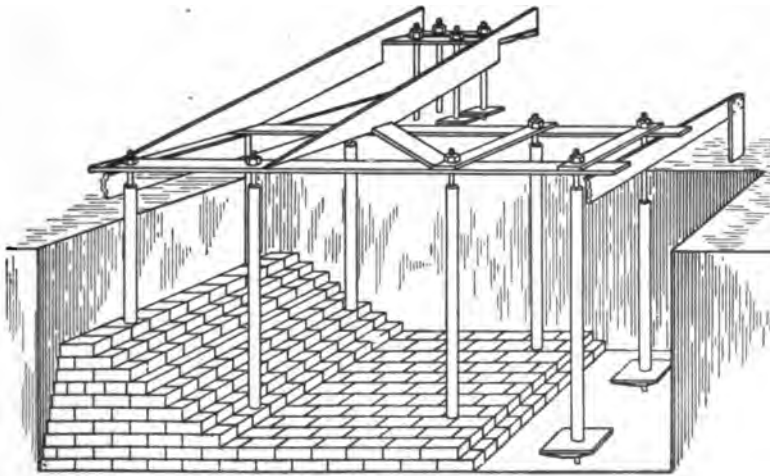


Fig. 2.

pipe that fixes them longitudinally but allows a little side play which may be necessary to enable them to enter the bed-plate

holes readily. The brickwork for machinery foundations should consist of hard burned bricks of first quality, *laid in good cement mortar*. Ordinary *lime mortar is entirely unfit* for the purpose, being likely to crumble away under the effect of the vibrations caused by the machinery. Brick or concrete foundations should be finished with a cap of bluestone or cement. This tends to hold the foundation together, and forms a level surface upon which to set the machinery. If the engine and generator are provided with a cast-iron sub-base, the capping may be dispensed with.

Fixing the Machine. In fixing either direct-connected or belt-driven machines, first determine, with a long straight edge and spirit level, if the top of the foundation is level and true. If this is found to be the case, the holding-down bolts may be dropped into the holes in the foundation, if they are not already built in, and the machine carefully placed thereon, the ends of the bolts being passed through the holes in the bed-plate and secured by a few turns of the nuts. The machine should then, if belt-connected, be carefully aligned with the transmitting pulley or fly wheel. Particular attention should be paid to the alignment of the pulleys in order that the belt may run properly. If direct-connected, the dynamo bed-plate and armature shaft must be carefully aligned and adjusted with respect to the engine shaft, raising or lowering the bed-plates of the corresponding machines by means of thin cast-iron or other wedges; and the generator frame should also be adjusted to its proper height by means of thin strips of metal or fiber set between its supporting feet and the bed-plate. Having thus aligned and leveled the machine, it should next be grouted with thin cement. This is done by arranging a wall of mud or wooden battens around the bed-plates of the machines, and running in thin cement until the holding-down bolt holes are filled, and the cement has risen to the level of the under side of the bed-plate. When the cement has set, the wall may be removed and the nuts on the holding-down bolts drawn up. This firmly fixes the machine upon its foundation.

Mechanical Connections. Various means are employed to connect the engine or other prime mover with the generator, or the motor with the apparatus to be driven. The most important are as follows:

Direct Connection.

Belting.

Rope Driving.

Toothed Gearing.

Other apparatus, such as shafting, clutches, hangers and pulleys, are used in connection with the above means.

Direct Connection. This is the simplest, and for that reason the most desirable, means of connection, provided it can be carried out without involving sacrifices that offset its advantages. This

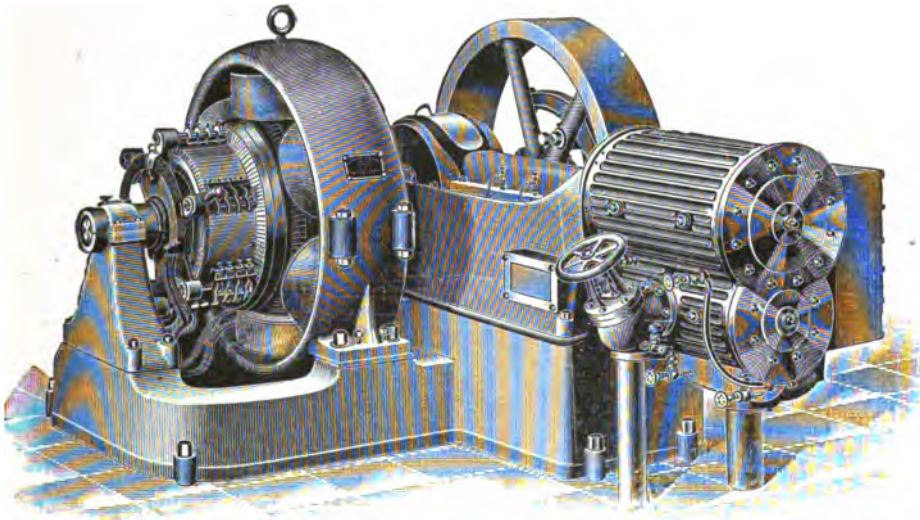


Fig. 3.

method, also called direct coupling or direct driving, compels the engine and generator to run at the same speed, which gives rise to some difficulty, as the most desirable speeds of the two machines do not usually agree. The natural speed of a generator is high, while that of an engine is low; hence to obtain the same voltage from a direct-connected generator, more inductors are necessary, or the flux cut must be increased. Accordingly, the armature and frame of the direct-connected generator must be larger, thus making it a more expensive machine than the belt-driven.

The direct connection of an engine and generator is accomplished in several ways; the simplest of which consists in mounting the armature of the generator directly on one end of the shaft of the engine. This may be accomplished in any one of several

ways. Fig. 3 represents the three-bearing method. Two-and-four-bearing methods are also used. These secure the great advantages: that accurate alignment is readily obtained, and space occupied reduced to a minimum, and the mounting of the bearings on a common sub-base avoids trouble due to unequal settling.

Another form of direct coupling is that in which an engine and a generator, each complete in itself, and each having two bearings, are coupled together by some mechanical device, which may be either rigid or slightly elastic or adjustable. In the former case

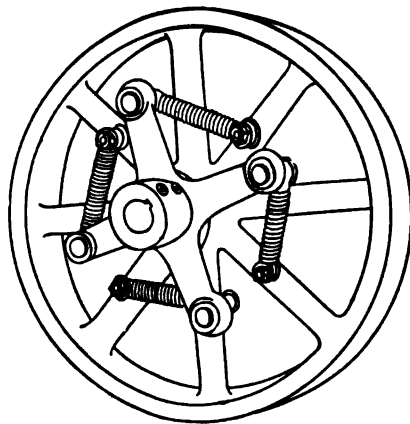


Fig. 4.

the two shafts are practically equivalent to a single one, which, while making it easy to remove either machine for repairs, is somewhat objectionable owing to the fact that it requires larger foundations, and introduces the difficulty of accurately aligning four bearings. The use of a flexible coupling avoids the necessity of perfect alignment, and also the serious trouble that might arise if the settling or the wear of the bearings should be un-

even. There are various forms of flexible coupling. One of the forms manufactured by the Westinghouse Machine Company is shown in Fig. 4, the flexibility being provided by the springs which hold the two parts of the coupling together.

The direct coupling of generators with turbines can be carried out without departing from the natural speed of either machine, since the ordinary speed of a turbine agrees closely with the normal speed of a generator of the corresponding capacity.

The relative efficiency of direct coupling and belting depends greatly upon the conditions; but in general the former is more efficient at or near rated load, and the latter at light loads. *The simplicity, compactness, and positive and noiseless action of direct connection* have caused it to become the most approved method.

Belting. If the generator or motor is not directly connected,

one to the prime mover and the other to the apparatus to be driven, they are usually connected by some form of belting. The kind of belting selected depends greatly upon conditions of drive, distances, etc.; and it may be leather, rawhide, rubber, or rope. For ordinary short drives, leather is the most desirable, though, when the power to be transmitted is small, rawhide belts are also satisfactory, especially as the cost is less than for leather belts. For considerable distances, rope driving answers very well because it is so much lighter and cheaper than an equivalent leather belt, though grooved pulleys are required, making the total cost about the same. Rubber belts are used to advantage in driving generators from water turbines, where the belt might be exposed to moisture. Leather belting is usually the most reliable and satisfactory for general application, except for very short drives, where a form of chain belt works best. There are three thicknesses of leather belting—single, light-double, and double. For use in connection with generators, motors, or other high-speed machinery, the “light-double” belting is usually the best.

The exact amount of power that a given belt is capable of transmitting is not very definite. The ordinary rule is that “single” belt will transmit 1 horse-power for each inch of its width when traveling at a speed of 1,000 feet per minute. If the speed is greater or less, the power is proportionately increased or decreased. The statement of H. P. transmitted is based upon the condition that the belt is in contact with the transmitting pulley around one-half of its circumference, or 180° , which is usually the case. If the arc of contact is less than 180° , the power transmitted is less in the following proportion: An arc of 135° gives 84 per cent, while 90° contact gives only 64 per cent of the power derived from a belt contact of 180° . If on the other hand, the upper side sags downward, which is always desirable, the belt is in contact with more than half the circumference of the pulley; and thus the grip is considerably increased and more power can be transmitted. These facts make it very desirable to have the *loose side of the belt on top*. If the loose side is below, it sags away from the pulley and is also likely to strike the floor.

The complete expression for determining the width of a single belt required to transmit a given horse-power is as follows:

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$$W = \frac{H. P. \times 1,000}{S \times C},$$

where W is the width of the belt in inches; $H. P.$ the horse-power to be transmitted; S the speed of the belt in feet per minute, which is equal to the circumference of the driving pulley in feet multiplied by the number of revolutions per minute;* and C a factor dependent upon the arc of contact.

"Double" belting is expected to transmit one and one-half ($1\frac{1}{2}$), and "light-double" one and one-quarter ($1\frac{1}{4}$) times as much power as "single" belting of the same width. Belting formulas are only approximate, and should not be applied too rigidly, since the grip of the belt upon the pulley varies considerably under different conditions of tension, temperature and moisture. The smooth side of a belt should always be run against the pulley, as it transmits more power and is more durable. Belting used for electric

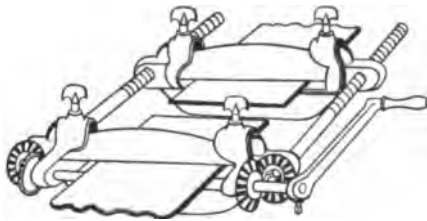


Fig. 5.

machinery, being usually high-speed, should be made "endless" for permanent work, as this makes less noise; but it may be used with laced joints, temporarily. A spliced or "endless" joint is made as follows:—Both ends of the belt are pared down on one side (opposite) with a sharp knife, into the form of a long thin wedge, so that when laid together a long uniform joint is obtained of the *same thickness as the belt itself*. The parts are then firmly joined with cement and sometimes with rivets also. It may be necessary to splice or lace a belt while in position on the pulleys; and for this purpose some form of belt clamp (Fig. 5) should be employed.

If a belt is ordered endless, or is spliced away from the pulleys, great care should be exercised in determining the exact length required. A string that will not stretch, or preferably a wire put around the pulleys in the position to be occupied by the belt, is the

* NOTE. Belts slip or "creep" on the pulley about 2 per cent; hence, in determining the size of pulleys whose speed must be accurate, the calculated belt speed should be about 2 per cent too high.

best way to avoid a mistake. In measuring for a belt, the generator or motor should be moved on its sliding base so as to make the distance between shaft centers a minimum, in order to allow for the stretch of the belt, which may be as much as $\frac{1}{2}$ inch per foot of length.

The lacing of a belt is a very simple and common method of making a joint; but should not be permanently employed at high speeds for electric machinery belting, as it is liable to pound on the pulleys, producing noise, vibration and sparking; and in the case of generators it is also likely to cause flickering in the lamps. In lacing belts, the ends should be cut perfectly square, and there should be as many stitches of the lace slanting to the left as there are to the right; otherwise the ends of the belt will shift

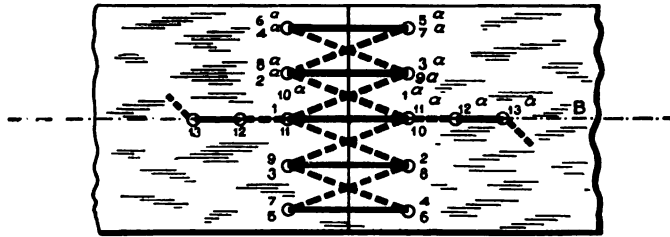


Fig. 6.

sidewise owing to the unequal strain, and the projecting corners may strike or catch in the clothing of persons. A good way to accomplish this is shown in Fig. 6. The various holes should be made with a circular punch, the nearest one being about $\frac{3}{4}$ inch from the side, and the line through the center of the row of holes about 1 inch from the end of the belt. In large belts these distances should be a little greater. A regular belt lacing of strong pliable leather or a special wire is used. The lacing is doubled to find its middle; and the two ends are passed through the two holes marked "1" and "1a," precisely as in lacing a shoe. The two ends are then passed successively through the two series of holes, in the order in which they are numbered, 2, 3, 4, etc., and 2a, 3a, 4a, etc., finishing at 13 and 13a, which are additional holes for securing the ends of the lace. The great advantage of this method of lacing is that the lace lies on the pulley side perfectly parallel to the direction of motion.

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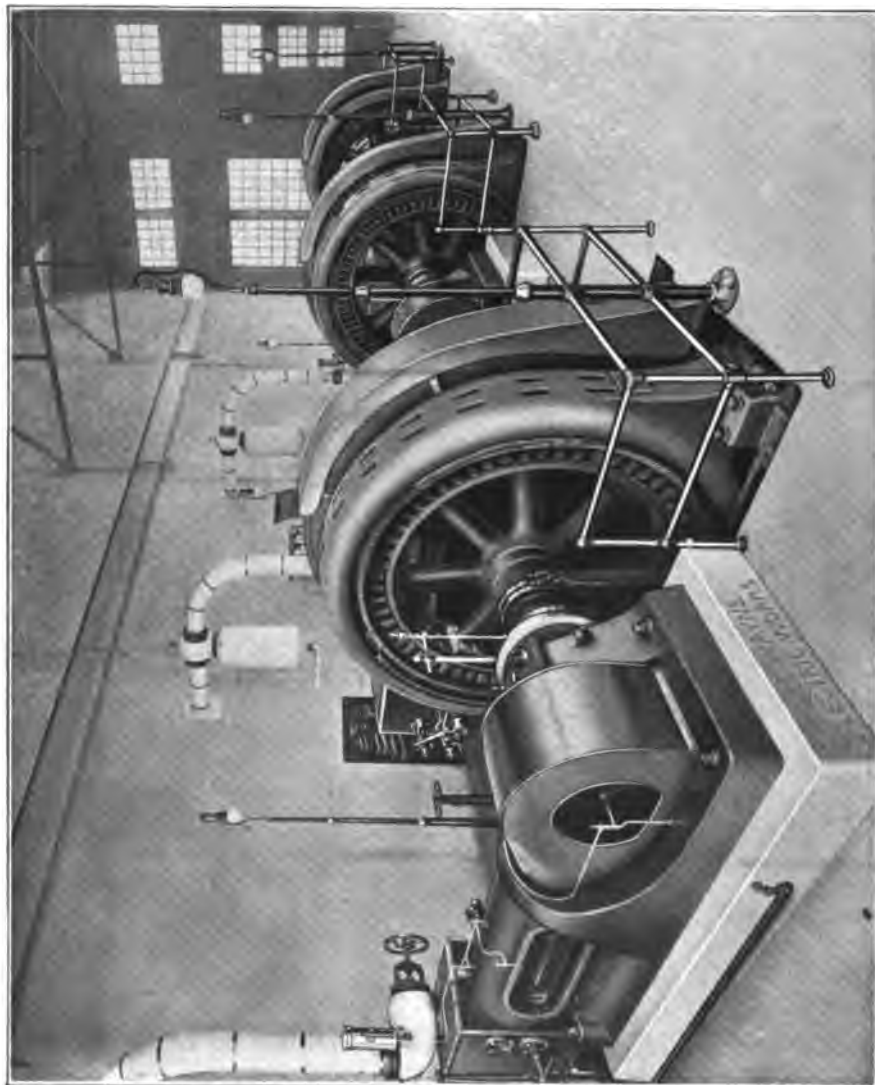
Perforated belts are often employed for the reason that a film of air is likely to be imprisoned between the belt and the pulley, thus preventing a good grip. Hence small perforations are sometimes made in the belt, especially for high-speed operation (3,000-5,000 feet per minute), to allow the air to escape; and since these are in the form of narrow slits, with their greatest dimension in the direction of motion, they do not materially reduce the strength of the belt.

Arrangement and Care of Belting. It is very desirable, for satisfactory running, that belts should be reasonably long and nearly horizontal. The distance between the centers of two belt-connected pulleys should be not less than 3 times the diameter of the larger pulley. The belt should be just tight enough to avoid slipping, without straining the shaft or bearings. The two shafts which are to be belt-connected must be perfectly parallel, and the centers of the face of the driving and driven pulleys must be exactly opposite to each other, in a straight line perpendicular to the axis of the shafts. The machines should then be turned over slowly with the belt on, to see if the latter tends to run to one side of the pulley, which would show that it is not yet properly "lined up," in which case one or both machines should be slightly shifted, until the belt runs properly. If possible, the machine and belt should be set and adjusted so as to cause the armature to move back and forth in the bearings while running, on account of the side motion of the belt, and thus make the commutator wear more smoothly, and distribute the oil in the bearings.

It is always desirable to have belts as pliable as possible; hence the occasional use of a good belt dressing—as neatsfoot oil, etc.—is recommended. Rosin and other sticky substances are sometimes applied to increase the adhesion; but this is a practice allowable only in an emergency, as it may destroy the belt surface.

In places where the belting is very much exposed, and liable to catch in the clothing of any person, it is advisable to surround it by a railing or box.

Rope Driving possesses advantages over ordinary belting in some cases. The rope runs in V-shaped grooves in the peripheries of the pulleys, and thereby obtains a great grip by a sort of wedging action. The kinds of rope ordinarily employed for this pur-



THREE MULTIPHASE ENGINE-DRIVEN FORT WAYNE ALTERNATORS
Two-Phase, Revolving Field, 240 Volts, 360 K. W.

pose are cotton, hemp, rawhide and wire. The general advantages are:

1. Economy in cost.
2. Large amount of power that can be transmitted with a given diameter and width of pulley, on account of the grip obtained.
3. It is almost noiseless.
4. Ropes, on account of their lightness, can be used to transmit power over greater distances than are possible with any other form of belting; and also for very short distances on account of the wedging action. Manila rope is generally used in the United States, being of three strands, hawser laid, and may be from $\frac{1}{2}$ inch to 2 inches in diameter. The breaking strength varies from 7,000 to 12,000 pounds per square inch of cross-section. It has been found that the best results are obtained when the tension in the driving side of the rope is only 3 to 4 per cent of the breaking strength.

The diameter of a single rope necessary to transmit a required H. P. is given by the formula:

$$D^2 = \frac{825 \text{ H. P.}}{V(200 - \frac{V^2}{1,072})}$$

in which H. P. = horse-power transmitted;

V = velocity of rope in feet per second;

D = diameter of rope in inches.

The maximum power is obtained at a speed of about 84 feet per second. With higher speeds the centrifugal force becomes so great that the power transmitted decreases rapidly, and at about 142 feet per second it counteracts the whole allowable tension (200 D² pounds) and no power is transmitted.

Arrangement of Rope Belting. There are two methods of arranging rope transmission: one consists in using several separate belts; and the other employs a single endless rope which passes spirally around the pulley several times and is brought back to the first groove by a slanting idle pulley, and therefore is called the "wound" system. The separate ropes do not require the carrying-over pulley, and if one rope breaks, those remaining are sufficient to transmit the power temporarily; whereas an accident with the single-rope system entirely interrupts the service. In

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the "multi-rope" system it is practically impossible to make and maintain the belts of exactly equal length, hence the tensions on the various ropes differ, and they hang at different heights on the slack side, producing an awkward appearance.

Toothed Gearing possesses the decided advantages of positive action and the ability to give large ratios of speed and small side pressure on the bearings. Nevertheless it is seldom employed for driving generators. As the most extensive applications of gearing for electrical purposes are in connection with railway motors, it will be taken up under that heading.

SHAFTING.

An intermediate or counter shaft is not desirable since it increases the complication and frictional losses of the system; but it is often necessary in the generation or application of electric power, either to obtain a greater multiplication of speed than is possible by belting directly, or to enable a single engine or motor to drive a greater number of machines.

The two important kinds of shaftings are "cold-rolled" and "turned." The former is rolled to the exact size and requires no further treatment. It has the advantage of a smooth, hard surface, but it is difficult to make perfectly true and straight. Turned-steel shafting is most commonly employed, and has the advantage that shoulders, journals, or other variations in size can be easily made on it. The following table gives the ordinary data for shafting:

TABLE I.

Shafting.

Diameter in inches.	Weight lbs. per ft.	Allowable H. P. transmitted at 100 r. p. m.	Width of key seat in inches.
$1\frac{7}{8}$	5.5	4.3	$\frac{3}{8}$
$1\frac{1}{2}$	10.	10.	$\frac{1}{2}$
$2\frac{1}{8}$	15.8	20.	$\frac{3}{4}$
$2\frac{1}{2}$	23.	34.	$\frac{3}{4}$
$3\frac{1}{8}$	31.5	54.	$\frac{7}{8}$
$3\frac{1}{2}$	41.	80.	1
$4\frac{1}{8}$	62.8	156.	1
$5\frac{1}{8}$	91.1	270.	1

With speeds greater than 100 r. p. m., the allowable H. P. varies directly in proportion to the speed employed.

ASSEMBLING OF THE MACHINE.

In unpacking and putting the machine together, great care should be used to avoid the least injury to any part, to clean scrupulously each part, and to put the parts together in exactly the right way. This care is particularly important with regard to the shaft, bearings, magnetic joints, and electrical connections, from

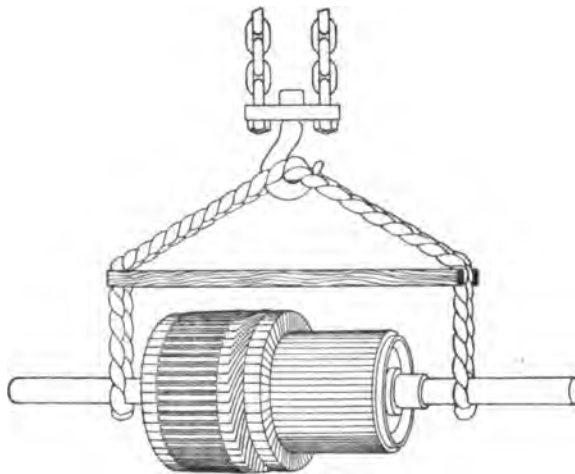


Fig. 7.

which every particle of grit, dust, metal chips, waste, etc., should be removed. It is advisable to study carefully the blue prints or instruction matter usually sent with each machine, before attempting to put it together. The armature must be handled with great care in order not to injure the wires and their insulation as well as the commutator and shaft. The armature should be handled as far as possible by the shaft, and when it must be placed on the ground a pad of cloth or layer of boards should be interposed. A convenient form of sling for handling armatures with their shafts in position is shown in Fig. 7. The bearings should be carefully cleaned, set in exactly the right positions, and firmly secured. The tops should be left loose for a short time, so that the tendency to heat up at the first run may be decreased; and after that they

should be drawn up tight. The field frame should be set so that the air gap is the same for all pole pieces, as otherwise the machine will be magnetically unbalanced and tend to spark badly.

The adjustment of the brushes, etc., should preferably be left until the machine is electrically connected and ready to receive its trial run.

METHODS OF WIRING.

Before laying the wires, the circuits should be carefully mapped out and the work so planned as to secure the simplest arrangement. The wiring should then be installed neatly and in accordance with the rules of the National Board of Fire Underwriters and of the local department having supervision. Otherwise unnecessary trouble, delay and expense may be incurred.

The wire may be installed in one of two general methods, *viz.*:

Exposed on	{	Cleats.
		Knobs.
		Bushings.
Concealed in	{	Wooden moulding.
		Iron conduit.
		Terra cotta conduit.

The wire should preferably be either rubber-covered or made up in the form of lead cables. Exposed wires possess the advantages of cheapness, as well as accessibility for inspection and repair; and any short circuit or ground is readily seen and removed, whereas it might cause great uncertainty and delay when the wires are concealed.

Concealed conductors, especially where they are placed under the floor, have the great advantage over exposed wiring, in that they are entirely out of the way. This is especially important in large installations, where overhead traveling cranes are almost a necessity.

When alternating-current conductors are enclosed in iron conduits, both wires of each phase, or all the wires, must be run in the same duct, otherwise the inductance would be excessive.

All conductors, including those connecting the machine with the switchboard, as well as the bus bars on the latter, should be of ample size to be free from overheating and excessive loss of voltage. The drop between the generator and switchboard should not exceed $\frac{1}{2}$ per cent at full load, because it interferes with proper

regulation and adds to the less easily avoided drop on the distribution system.

The safe carrying capacities of copper conductors as recommended by the Board of Fire Underwriters, are given in the following table:

TABLE II.
Safe Carrying Capacities of Copper Wires.

B. & S. G.	Rubber Insulation. Amperes.	Other Insulations. Amperes.	Circular Mils.
18.....	3.....	5.....	1,624
16.....	6.....	8.....	2,583
14.....	12.....	16.....	4,107
12.....	17.....	23.....	6,530
10.....	24.....	32.....	10,380
8.....	33.....	46.....	16,510
6.....	46.....	65.....	26,250
5.....	54.....	77.....	33,100
4.....	65.....	92.....	41,740
3.....	76.....	110.....	52,630
2.....	90.....	131.....	66,370
1.....	107.....	156.....	83,690
0.....	127.....	185.....	105,500
00.....	150.....	220.....	133,100
000.....	177.....	262.....	167,800
0000.....	210.....	312.....	211,600
Circular Mils.			
200,000.....	200.....	300.....	
300,000.....	270.....	400.....	
400,000.....	330.....	500.....	
500,000.....	390.....	590.....	
600,000.....	450.....	680.....	
700,000.....	500.....	760.....	
800,000.....	550.....	840.....	
900,000.....	600.....	920.....	
1,000,000.....	650.....	1,000.....	
1,100,000.....	690.....	1,080.....	
1,200,000.....	730.....	1,150.....	
1,300,000.....	770.....	1,220.....	
1,400,000.....	810.....	1,290.....	
1,500,000.....	850.....	1,360.....	
1,600,000.....	890.....	1,430.....	
1,700,000.....	930.....	1,490.....	
1,800,000.....	970.....	1,550.....	
1,900,000.....	1,010.....	1,610.....	
2,000,000.....	1,050.....	1,670.....	

The lower limit is specified for rubber-covered wires to prevent gradual deterioration of the high insulations by the heat of the wires, but not from fear of igniting the insulation. The question of drop is not taken into consideration in the above tables.

The carrying capacity of Nos. 16 and 18, B & S. gage wire is given, but no smaller than No. 14 is to be used.

The safe carrying capacity of insulated aluminum wire is 84 per cent of that given for copper wires of corresponding size and insulation.

Switches are devices for closing and opening the various circuits or branches of an electrical distribution system. A knife switch should always be employed when the capacity of the circuit to be controlled exceeds 10 amperes. It may be single-, double-, or triple-pole; single- or double-throw; and with or without fuses as desired. If the rated capacity of a switch exceeds 25 amperes, its terminals must be provided with lugs into which the ends of the conducting wires should be soldered. The principal parts of a knife switch (Fig. 8) are the *base* (*a*), which must consist of a non-combustible, non-absorptive insulating material; the *hinges* (*b*), which carry the *blades* (*c*); the *contact jaws or clips* (*d*); the *insulating cross-bar* (*e*); and the *handle* (*f*).

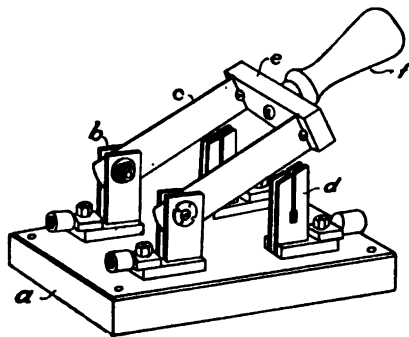


Fig. 8.

The hinges, blades and jaws should be made of pure copper, of sufficient cross-section to insure mechanical stiffness and proper carrying capacity, and their contact surfaces must not be less than 1 square inch per 75 amperes of the rating. The hinges and contact jaws must be springy enough to insure good contact with the blades. The blades and jaws must be so shaped

that they open along their entire length simultaneously; otherwise the arc which is formed upon opening a loaded circuit, will burn off the last points of contact. In fact this arc, when produced by a heavy current, is very difficult to control; and switches should never be opened on heavily-loaded circuits except in an emergency. In practice, however, some form of electro-magnetic circuit-breaker is employed for the purpose, and may be operated automatically with overload, or by hand at any time.

Knife switches should be so placed that *gravity tends to open* rather than to close them. They should always be located in dry, accessible places and grouped as far as possible. If located in ex-

posed positions they should be enclosed in slate or equivalently lined cabinets. The distances between the parts of opposite polarity, in an approved knife switch, must never be less than the values given in the following table:

TABLE III.

Switch Data.

125 VOLTS OR LESS :	Minimum Separation of Nearest Metal Parts of Opposite Polarity.	Minimum Break Distance.
<i>For Switchboards and Panel Boards—</i>		
10 amperes or less.....	$\frac{3}{4}$ inch	$\frac{1}{8}$ inch.
11-25 “.....	1 “	$\frac{3}{8}$ “
26-50 “.....	$1\frac{1}{4}$ “	1 “
<i>For Individual Switches—</i>		
10 amperes or less.....	1 inch	$\frac{3}{4}$ inch.
11- 35 “.....	$1\frac{1}{4}$ “	1 “
36- 100 “.....	$1\frac{1}{2}$ “	$1\frac{1}{4}$ “
101- 300 “.....	2 $\frac{1}{4}$ “	2 “
301- 600 “.....	2 $\frac{3}{4}$ “	2 $\frac{1}{2}$ “
601-1,000 “.....	3 “	2 $\frac{3}{4}$ “
126 TO 250 VOLTS :		
<i>For all Switches—</i>		
10 amperes or less.....	$1\frac{1}{4}$ inch	$1\frac{1}{4}$ inch.
11- 35 “.....	$1\frac{3}{8}$ “	$1\frac{1}{2}$ “
36- 100 “.....	2 $\frac{1}{4}$ “	2 “
101- 300 “.....	2 $\frac{1}{2}$ “	2 $\frac{1}{4}$ “
301- 600 “.....	2 $\frac{3}{4}$ “	2 $\frac{1}{2}$ “
601-1,000 “.....	3 “	2 $\frac{3}{4}$ “

On switchboards, the above spacings for 250 volts direct current are also approved for 440 volts alternating current. Switches on switchboards with these spacings intended for use on alternating-current systems with voltages above 250, must be stamped with the voltage for which they are designed, followed by the letters “A. C.”

251 TO 600 VOLTS :

For all Switches—

10 amperes or less.....	$3\frac{1}{2}$ inch	3 inch.
11- 35 “.....	4 “	$3\frac{1}{2}$ “
36-100 “.....	$4\frac{1}{2}$ “	4 “

Auxiliary breaks or the equivalent are recommended for switches designed for over 300 volts and less than 100 amperes, and will be required on switches designed for use in breaking currents greater than 100 amperes at a pressure of more than 300 volts.

For three-wire systems switches, must have the break-distance required for circuits of the potential of the outside wires.

Safety Fuses and Cut-outs. Almost all electrical circuits, except those for constant-current arc lighting, are protected from abnormal increase of current by safety fuses. These consist of wires or strips of metal introduced into the circuit, and so designed in cross-section and resistance that they will melt and open the circuit in case of excessive current, before the rest of the system becomes unduly heated.

The requirements for effective safety fuses may be stated as follows:

1. They should melt at a definite current.
2. They should not change in this respect by the effect of time, nor by heating or other action of the current, nor, in fact, under any reasonable conditions.
3. They should act promptly.
4. They should give firm and lasting contacts with the terminals to which they are attached.

These fuses are of two general types:

- (a) Open or link fuses.
- (b) Enclosed or cartridge fuses.

The open or link fuses (Fig. 9) consist of strips of fusible



Fig. 9.



Fig. 10.

alloy provided with copper terminals. Each size is designed to carry a certain normal current, but will melt and open the circuit when the current exceeds that rating by 25 per cent. When a link fuse "blows" as a result of overloading, the rupture is accompanied by a flash, and by spattering of the fused material. With large currents this phenomenon is a source of danger, and the use of enclosed fuses is accordingly recommended whenever the rating of the fuse exceeds 25 amperes.

Enclosed fuses (Fig. 10) have a casing around the fusible material, which prevents the dangerous spattering and which also smothers the arc that tends to form whenever a fuse blows.

Fuses should always be employed when the size of the wire changes, or where connections between any electrical apparatus and

the conductors are made. They must be mounted on slate, marble, or porcelain bases; and all metallic fittings employed in making electrical contacts must have sufficient cross-section to insure mechanical stiffness and carrying capacity.

Electro-magnetic Circuit-Breakers or **Limit Switches** are frequently used in place of fuses to protect electrical circuits. Their

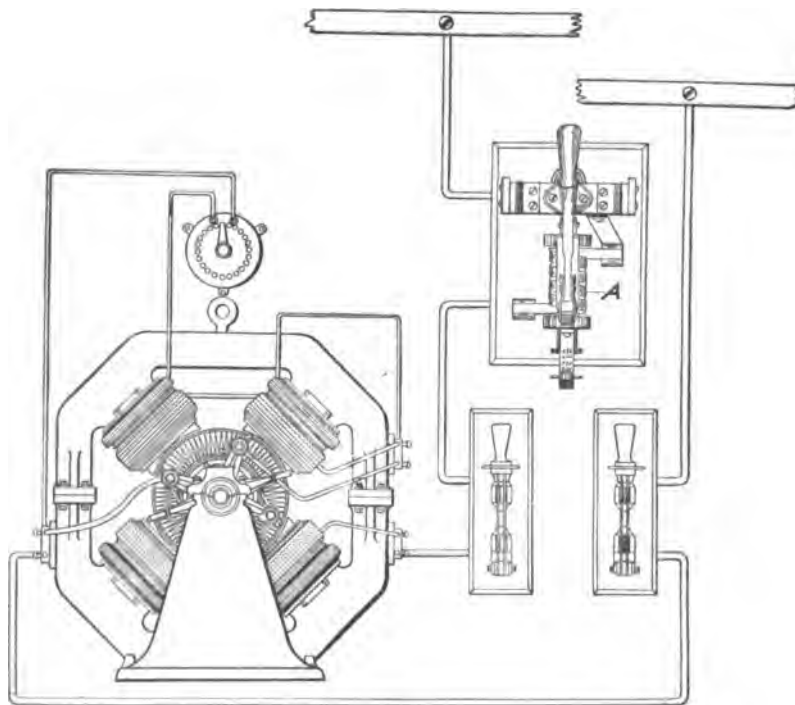


Fig. 11.

general construction and application are indicated in Fig. 11. The current is led through a helix A the electro-magnetic action of which, when the current reaches a predetermined limit, automatically releases the blades from contact with the jaws and thus opens the circuit. The final break occurs at carbon tips, thus preventing destructive arcing at the copper contacts. Circuit-breakers possess the following advantages over fuses:

1. They can be employed as switches if desired.
2. They can easily be reset and thus put into condition for acting again.

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3. Their range can be easily varied within considerable limits.
4. They can also be made to operate "tell tales" whenever the circuit they control is opened.

On account of these general advantages, their use is advisable on switchboards of systems that are liable to frequent overloads. The circuits, however, should, as a rule, be provided also with fuses, since it is possible that the circuit-breaker may fail to open, owing to corrosion or other cause.

Starting-Boxes should always be furnished with D. C. motors, for the following reason: If the line voltage should be applied directly to the terminals of the armature while it is standing still, a very excessive current would flow, since the resistance is low and no C. E. M. F. exists. Hence, to prevent injury to the winding, a resistance is inserted between one supply terminal and the armature in order to reduce the electromotive force at the motor terminals while it is speeding up, the resistance being gradually reduced until completely removed when rated speed is reached. All motor starting-boxes must also be provided with a **no-voltage release**. This consists of an electro-magnet in series with the shunt-field circuit, which holds the rheostat arm in the operating position as long as current flows through the shunt field from the line. If the line switch be opened or the shunt-field circuit accidentally broken, the device becomes demagnetized and releases the arm, which returns to its starting position (all resistance in circuit) by the action of a spring or of gravity. The starting-boxes of larger motors are also frequently equipped with **overload releases**. These, practically, are electro-magnetic circuit-breakers which open the supply lines if the motor becomes greatly overloaded. The general arrangement of switches, cut-outs and starting-boxes should be in accordance with the following extract from the Rules of the National Board of Fire Underwriters:

"Each motor and starting-box must be protected by a cut-out and controlled by a switch, said switch plainly indicating whether 'on' or 'off.' The switch and rheostat must be located within sight of the motor, except in cases where special permission to locate them elsewhere is given, in writing, by the Inspection Department having jurisdiction.

"Where the circuit-breaking device on the motor-starting rheostat disconnects all wires of the circuit, this switch may be omitted.

"Overload-release devices on motor-starting rheostats will not be considered to take the place of the cut-out required if they are inoperative during the starting of the motor.

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“The switch is necessary for entirely disconnecting the motor when not in use; and the cut-out, to protect the motor from excessive currents due to accidents or careless handling when starting. An automatic circuit-breaker disconnecting all wires of the circuit, may, however, serve as both switch and cut-out.”

The Various Kinds of Circuit on which motors and generators are commonly used, and the best type of machine in each case, are as follows :

TABLE IV.

Types of Machine for Various Kinds of Circuits.

DIRECT-CURRENT, CONSTANT-POTENTIAL.

Circuits on which potential or voltage is kept constant; machines, lamps, etc., being run in parallel.

Currents intended for—	Potential.	Generator should be—	Motor should be—
Electro-metal-lurgy.	1 to 150 volts	Shunt-wound.	Not used.
Incandescent lighting.	$\left\{ \begin{array}{l} 110 \text{ to } 125 \text{ volts} \\ \text{(2-wire sys.)} \\ 220 \text{ to } 250 \text{ volts} \\ \text{(2-or 3-wire sys.)} \end{array} \right\}$	Shunt- or compound-wound.	Shunt-wound for constant speed. Sometimes series- or compound-wound for variable speed.
Electric railway Electric power.	$\left\{ \begin{array}{l} 500 \text{ to } 660 \text{ volts} \end{array} \right\}$	Compound-wound.	Series-wound for railway. Shunt-wound for stationary.

DIRECT, CONSTANT-CURRENT.

Circuits on which current or amperes are kept constant; machines, lamps, etc., being run in series.

Circuits intended for—	Current in Amperes.	Generator should be —	Motor.
Arc lighting.	6.8 or 9.6	Series-wound with current regulator.	No longer used.

ALTERNATING-CURRENT, POLYPHASE.

Constant-potential, two- or three-phase currents.

Circuits intended for—	Potential in Volts.		Generator should be—	Motor is—
Power transmission.	On the line, 5,000 to 60,000.	In the machines, varying 500 to 12,000	Separately excited.	Synchronous or Induction.

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ALTERNATING-CURRENT, SINGLE-PHASE.

Almost always constant-potential.

Circuits intended for—	Potential in Volts.		Generator should be—	Motor should be—
	Primary, 1,000 or more,	Secondary, 104 or 208.		
Incandescent lighting. Arc lighting. Sometimes constant-current. Electric power.			Separately excited. Also some- times composite- wound.	Synchronous. Induction. Series. Repulsion.

Diagrams of Connections are given for each important case to show what is actually required. These merely represent the path of the currents in the simplest way, the important thing being to have these paths right, and to know which parts or wires are to be connected. The case of plants operating with only a single generator will be first considered, and then the parallel or series operation of several machines described.

Shunt Dynamo, Supplying Constant - Potential Circuit.

A machine of the above type is represented in Fig. 12, with the necessary connections. The brushes are connected to the two conductors forming the main circuit; also to the field-magnet coils *Sh* through a resistance-box *R*, to regulate the strength of current

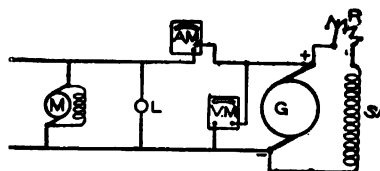


Fig. 12.

and therefore the magnetism in the field. A voltmeter is also connected to the two brushes or main conductors, to measure the voltage or electrical pressure between them. One of the main conductors is connected through an ammeter *A*, which measures the total current on the main circuit. The lamps *L*, or motors *M*, are connected in parallel between the main conductors or between branches from them. This represents the ordinary low-tension system for electric light and

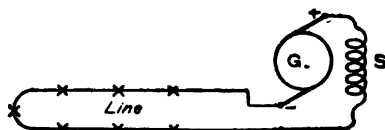


Fig. 13.

power distribution from isolated plants or central stations.

Series Dynamo Supplying Constant-Current Circuits. The connections in this case are extremely simple, the armature, field coils, ammeter, main circuit, and lamps all being connected in one series (Fig. 13), the current being kept constant. This system is used for series D. C. arc lighting.

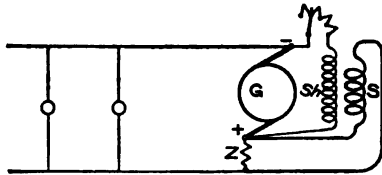


Fig. 14.

Compound Direct - Current Dynamo. This machine is a combination of the two foregoing types as regards field wind-

ing; but its load of lamps and motors are connected in parallel, as shown in Fig. 14. The resistance Z is known as the "series" shunt, and is for adjusting the percentage of compounding. The greater the resistance of Z , the greater the current passing through the series field, and the greater the compounding. This type of machine is most extensively employed in electric railway and in isolated plant work.

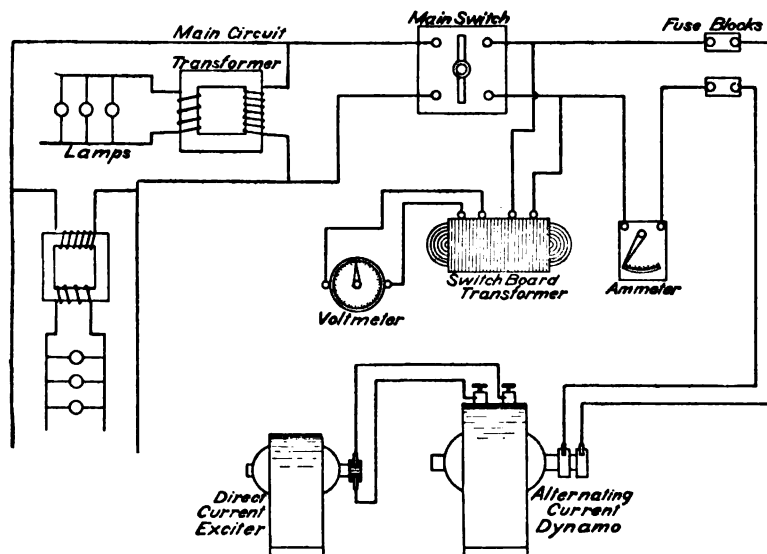


Fig. 15.

Alternating-Current Plants. The connections for a single-phase installation are shown in Fig. 15, in which the names of the

different parts are given. This system is extensively used for lighting over considerable distances, and is very well adapted to street railway work. The wiring of a two-phase system is essentially double that given above, and can be treated as a system consisting of two single-phase circuits.

The wiring of a three-phase system is as shown in Figs. 16a and 16b, the former being known as the "Y" system or "Star"

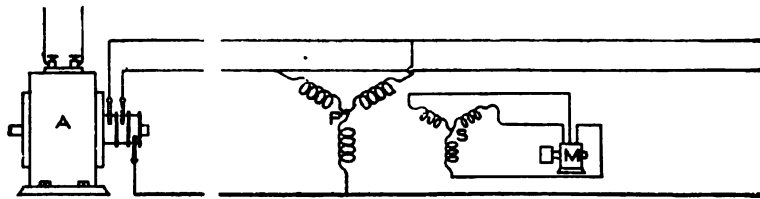


Fig. 16a.

system, and the latter as the "Delta" (Δ) system or "Mesh" system. When the Y system is required for both lighting and power, it is arranged as shown in Fig. 16c.

The **Direction of Rotation** of the various machines is sometimes a matter of doubt or trouble. Almost any generator or motor is intended to be run in a certain direction; that is, it is called "right-handed" or "left-handed" according to whether the armature does or does not revolve like the hands of a clock, when looked at from the pulley end. Generators and motors are usually

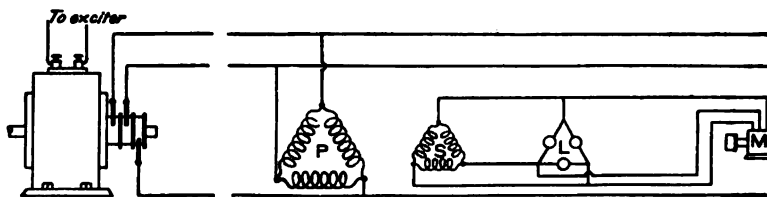


Fig. 16b.

designed to be right-handed, but the manufacturer will make them left handed if specially ordered. This may be required because the other pulley to which the machine is to be connected happens to revolve left-handed; or it may be necessary in order to bring the loose side of the belt on top, or to permit the machine to occupy a certain position where space is limited.

To reverse the direction of rotation of an ordinary shunt (or series) direct-current bipolar motor, the brushes may simply be reversed as indicated in Fig. 17, without changing any connection. This changes the point of contact of each brush tip 180° .

If the machine is multipolar, a similar change must be made, amounting to 90° in a four-pole, 45° in an eight-pole machine, etc.

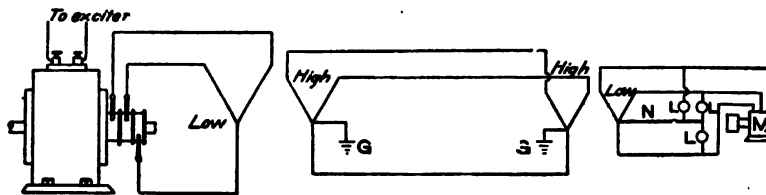


Fig. 16c

The direction of the current and the polarity of the field magnets remain the same as before; all that is changed is the direction of rotation and the position of the brushes. This applies to any machine (either motor or generator) except arc dynamos and one or two other peculiar machines, which require to be run in a certain direction to suit the regulating apparatus.

A separately excited alternating-current generator can be reversed in direction of rotation without changing any connection. A self-exciting or compound-wound alternator requires the brushes that supply the direct current to the field to be reversed upon the

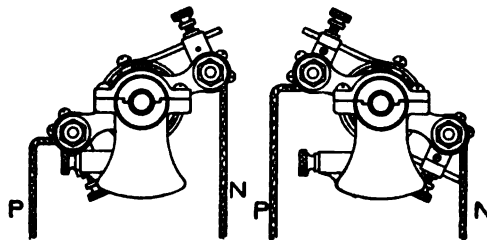


Fig. 17.

commutator, and their tips moved through an angle as above stated, if the rotation is to be reversed.

In any case, copper brushes (unless they be gauze brushes pressing radially upon the commutator) should point in the direction of rotation; but carbon brushes, particularly if they are per-

pendicular to the surface of the commutator, allow the armature to be revolved in either direction.

If the direction of the current from a generator is opposite to that desired, the two wires leading from it should exchange places in the terminals. If this is not desirable, the residual magnetism may be reversed by passing through the field winding a current opposite in direction to the original current.

Changing the direction of the current by reversing the main wires or otherwise, does not reverse the direction of rotation of any motor, since it reverses *both* the armature and the field. The way to reverse the direction of rotation is to reverse *either* the armature or the field connection *alone*, leaving the other the same as before.

Examination before Starting. The machine should be cleaned throughout, especially the commutator, brushes, electrical connections, etc. Any metal dust on the commutator or near electrical connections should be removed, as it is very likely to cause short circuits or grounds. Examine the machine carefully, and make sure that there are no screws or other parts that are loose or out of place. See that the oil-cups have a sufficient supply of oil, that the passages for the oil are clean, and that the feed is at the proper rate. In the case of self-oiling bearings, the rings or other means for carrying oil should work freely. See that the belt, if used, is in place, and that it has the proper tension. If the machine is being started for the first time, it should be turned a few times by hand, or run very slowly, in order to determine whether the shaft revolves easily and the belt runs on centers of pulleys.

The brushes should be carefully examined, and adjusted to make good contact with the commutator at the proper point, the switches connecting the machine to the circuit being left open. The machine should then be started with care, and brought up to full speed gradually, if possible. The person who starts either a dynamo or a motor should closely watch the machine and everything connected with it, and should be ready to throw it out of circuit and stop it instantly if the least thing seems to be wrong. He should then be sure to find out and correct the trouble before starting again.

Starting a Generator. A generator is usually brought up to



CROCKER-WHEELER 900-K. W., 550-VOLT D. C. RAILWAY GENERATOR
In Plant of Consolidated Railway Co., New Haven, Conn.

speed either by starting its engine or other prime mover, or by connecting it to a source of power already in motion. The former should be attempted only by a person competent to manage steam engines or the prime mover in question. The mere mechanical connecting of a generator to a source of power is usually not difficult; but it should be done carefully and intelligently, even if it only requires throwing in a friction-clutch or shifting a belt from an idle pulley. To put a belt on a pulley in motion is difficult and dangerous, particularly if the belt is large or the speed is high; and should not be tried except by one who knows just how to do it. Even if a stick is used for this purpose, it is apt to be caught and thrown around by the machinery unless used in exactly the right way.

In many cases generators are brought to full speed before the brushes are put in contact with the commutator; but this is not necessary. If the brushes are in contact before starting, they can be more easily and perfectly adjusted, and the E. M. F. will come up slowly, so that any fault or difficulty will develop gradually and can be corrected, or the machine stopped, before any injury is done. In fact, if the machine is working alone on a system, and is absolutely free from any danger of short-circuiting any other machine or storage battery on the same circuit, it may be started while connected to the circuit, but not otherwise (see next article). With a large number of lamps connected to the circuit, the field magnetism and voltage might not be able to "build up" until the line is disconnected.

If one generator is to be connected to another or to a circuit having other generators or a storage battery working upon it, the greatest care should be taken. This coupling together of generators can be done perfectly, however, if the correct method is followed, but is likely to cause serious trouble if any mistake is made.

Two or more machines are often connected to a common circuit. This is especially the case in central stations where the load varies so much that, while one generator may be sufficient for certain hours, two, three, or more machines may be required at other times. The various ways in which this is done depend upon the character of the machines and of the circuit.

Generators may be connected together either in parallel or in series.

Generators in Parallel. In this case the $+$ (positive or plus) terminals are connected together or to the same line, and the $-$ (negative or minus) terminals are connected together or to the other line. The currents (*i. e.*, amperes) of the machines are thereby added, but the E. M. F. (volts) is not increased. The chief condition for the running of generators in parallel is that their voltages shall be equal, but their current capacities may be different.

For example: A generator producing 10 amperes may be connected to another generating 100 amperes, provided the voltages agree. Parallel working is therefore suited to constant-potential circuits. A generator to be connected in parallel with others or with a storage battery, must first be brought up to its proper speed, E. M. F., and other working conditions; otherwise it will short-circuit the system, and might burn out its armature. Hence it should not be connected to a circuit in parallel with others until its voltage has been tested and found to be equal to, or slightly (not over 1 or 2 per cent) greater than, that of the circuit. If the voltage of the dynamo is less than that of the circuit, the current will flow back through it and cause it to run as a motor. The direction of rotation is the same, however, if it is shunt-wound; and no great harm results from a slight difference of potential; but compound-wound machines require more careful handling.

Direct-Current Dynamos in Parallel are always Shunt-Wound (or Compound-Wound). The test for equal voltages may be made by first measuring the E. M. F. of the circuit and then of the machine by one voltmeter; or two voltmeters, one connected to each, may be compared (Fig. 18); or a differential voltmeter may be used. Another method is to connect the dynamo to the circuit through a high resistance and a galvanometer; and when the latter indicates no current, it shows that the voltage of the dynamo is equal to that of the circuit. A rougher and simpler way to do this is to raise the voltage of the dynamo until its "pilot-lamp," or other lamp fed by it, is fully as bright as the lamps on the circuit, and then to connect the dynamo to the cir-

cuit. Of course the lamps compared should be intended for the same voltage and in normal condition. Be sure to connect the positive terminal of the dynamo to the positive conductor, and the negative terminal to the negative conductor (Fig. 18); otherwise there will be a very bad short circuit.

When the dynamo is first connected in this way, it should supply only a small amount of current to the circuit (as indicated by its ammeter), and its voltage should then be gradually raised until it generates its proper share of the total current; otherwise it will cause a sudden jump in the brightness of the lamps on the circuit.

Series-Wound Dynamos in Parallel Not Used. If the machine is series-wound, the back current just described would cause a reversal of field magnetism and a very bad short circuit of double voltage. In fact,

series dynamos in parallel are in unstable equilibrium, because if either tends to generate too little current, its own field, which is in series, is weakened, and thus still further reduces its current and probably will reverse the machine. This arrangement is therefore not used. One way in which this difficulty might be overcome is by causing each to excite the other's field magnet, so that if one generates too much current, it strengthens the field of the other and thus counteracts its own excess of power.

Another plan is to excite both fields by one machine, or, better, by both machines jointly, which is accomplished by connecting together the two + brushes and the two - brushes respectively, by the line and by what is called an *equalizer* (Fig. 19). In this way the electrical pressure at the terminals of the two armatures is made the same, and the currents in the two fields are also made equal. Series machines are not often run in parallel, but the principles just explained help the understanding of the next case, which is very important.

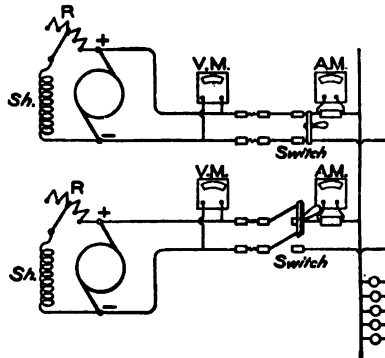


Fig. 18.

Compound Dynamos in Parallel. Since the field magnets of these machines are wound with series coils as well as with shunt coils, the coupling of them is a combination of the shunt and series cases just described.

The manner of connecting two or more compound dynamos to operate in parallel, is represented in Fig. 20, A being the armature, B the series, and C the shunt-field coils. R is the shunt-field

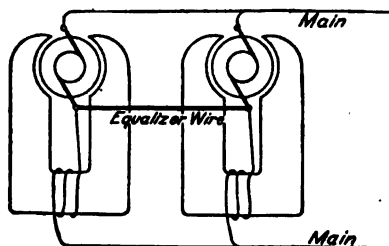


Fig. 19.

rheostat; D and F are switches connecting the main terminals of the machine with the bus bars G and I, respectively; and E is a switch to connect the equalizer H with the brush end of the series coil B.

Assume that machine No. 1 is already in operation with its switches D, F, and E closed, and

that it is desired to have machine No. 2 thrown in circuit. The procedure is as follows:

Bring machine No. 2 up to its rated speed, and adjust its pressure by means of the shunt-field rheostat until it is a little greater (about 1 per cent) than the difference of potential between the bars G and I. This fact may be ascertained by comparing two voltmeters connected to the dynamo and to the bus bars respectively; or by means of a single voltmeter connected through a double-throw switch, first to one and then to the other, which avoids the error due to a difference between two instruments. Another plan is to employ a differential voltmeter, that is, one having two windings on the movable coil, so that it indicates directly the difference in voltage between the two parts of the system.

After the pressure of the *incoming* dynamo has been properly regulated, the three switches E, F, and D are closed in the order named. If these points should be closed simultaneously by means of a triple-pole switch, a considerable current might flow through the series field winding, tending to increase still further the voltage of this dynamo, at the same time taking current away from the series coils of the other machines, and thereby reducing their potential. The shifting of the load thus produced might be so

sudden and so great as to be objectionable. This action, however, is not of sufficient importance to overbalance the many advantages afforded by the use of a switch in which the three are combined as a triple-pole switch, thus guarding against the possibility of any accident due to closing the wrong circuit first.

After the machines have been thrown in parallel, their volt-

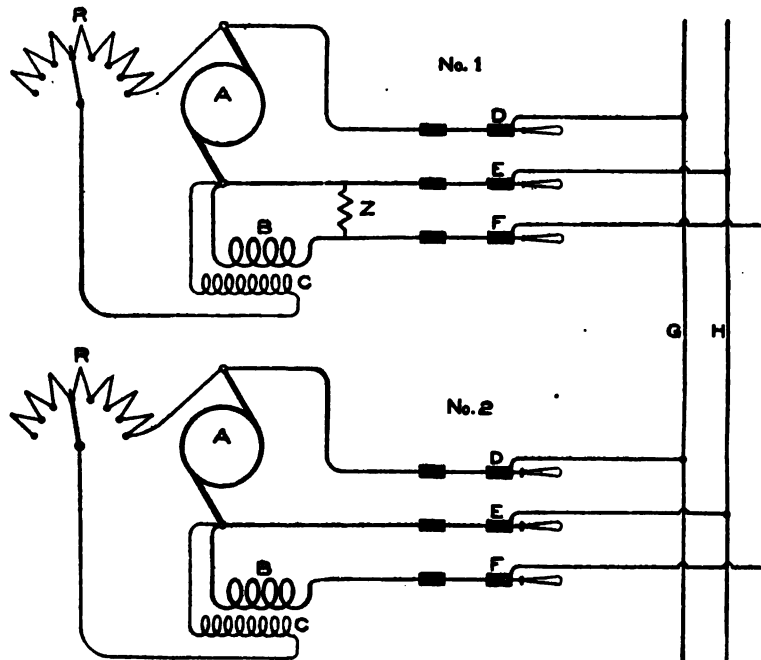


Fig. 20.

ages should be adjusted by the shunt-field rheostats so that the load is properly divided between them.

Compound dynamos of different size or current capacity may also be coupled as described, provided, of course, their voltages are equal; and provided also that the resistances of the series field coils, together with their leads to the bus bar, are inversely proportional to the current capacities of the several machines; that is, if a dynamo produces twice as much current, its series coil and lead should have half the resistance. It is further necessary that the two machines should agree in their action, so that a given increase in load will produce the same effect upon their voltages.

If they are not in agreement, they may be adjusted by slightly increasing the resistance of the series coil of that machine which tends to take too large a share of the load. This may be done by simply interposing a few extra feet of conductor of the same current capacity as the series coil, between the latter and the main conductor or bus bar. The shunts which are almost always used to adjust the effect of the series coils in compound dynamos (shown at Z in machine No. 1, Fig. 20), operate properly in the case of machines working *singly*, but are worthless for machines in parallel. The *resistances of the series coils themselves* must be adjusted as explained above, when two or more compound machines are run in parallel. The use of iron for this shunt makes the compounding effect in the dynamo more uniform, because its resistance, rising as the current through it increases, throws a greater fraction of the current through the series coils at full load, and compensates for the fact that the field magnetism, and consequently the voltage, does not increase proportionately with the increasing load current.

Shunt-wound dynamos run in parallel tend to steady each other, for, if one happens to run too fast, it has to do more work, which opposes the increase of speed; and it also takes part of the load off the other machines, which makes them run faster, thus producing equality. This mutual regulation will take care of any slight difference between machines, such as that caused by the slip of the belt, or even small differences in the governing action of the different engines that may be driving them. Compound-wound dynamos have very much less mutual regulation, owing to the effect of the series coil; and it is necessary that their speeds, voltages, etc., should regulate much more exactly than with simple shunt machines. They often work badly together owing to carelessness or to imperfect agreement between them, but with proper care and good apparatus they run well in parallel.

If generators are located at considerable distances from the switchboard, the equalizing connection may be run directly from one machine to the other with the equalizing switch (E, Fig. 20) on the frame of each, instead of running to the switchboard. This saves copper, especially in the case of large generators.

Alternators in Parallel. To run two alternators in parallel,

several conditions have to be fulfilled: The incoming machine—as in the case of direct-current machines—must be brought up to nearly the same voltage as the first one; it must operate at exactly the same frequency; and, at the moment of switching in parallel, it must be in phase with the first machine. This correspondence of frequency and phase is called **synchronism**.

It is impossible with mechanical speed-measuring instruments to determine the speed as accurately as is necessary for this purpose. There is, however, a very simple method of electrically determining small differences in speed or frequency. In Fig. 21, let M and N represent two single-phase alternators, which can be connected by means of the single-pole switch AB. Across the terminals of the switch is connected an incandescent lamp L, capable of standing twice the voltage of either machine. When AB is open, the circuit between the machines is completed through L. The two machines may be connected in parallel as follows:

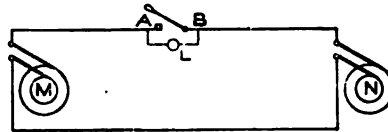


Fig. 21

Assuming machine M already in operation, bring up machine N to approximately the proper speed, and voltage; then watch lamp L. If machine N is running a very little slower or faster than machine M, the lamp L will glow for one moment and be dark the next. At the instant when the voltages are equal in pressure and phase, L will remain dark; but when the phases are displaced by half a period, the lamp will glow at its maximum brilliancy. Since the flickering of the lamp is dependent upon the difference in frequency, the machines should not be thrown in parallel while this flickering exists. The prime mover of the incoming machine must be brought to the proper speed; and the nearer machine N approaches synchronism, the slower the flickering. When it is very slow, we can use the moment the lamp is dark to throw the machines in parallel by closing the switch across AB. The machines are then in phase, and tend to remain so, since if one slows down the other will drive it as a motor. It is better to close the switch when the machines are approaching synchronism than when they are receding from it, that is, at the instant the lamp becomes dark.

This method of synchronizing is open to the following objections:

- (a) The lamps may be dark with considerable difference in voltage. For instance, a 110-volt lamp is dark with a pressure of 20 to 25 volts.
- (b) The lamp may be dark owing to a broken filament.

It may thus happen, with this arrangement, that the ma-

chines are placed in parallel while there is a considerable difference of voltage or phase existing, and an excessive rush of current will result.

A method not open to the above objections is shown in

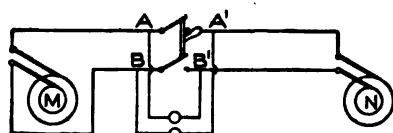


Fig. 22

Fig. 22. The machines to be switched in parallel are each connected to the bus bars by means of double-pole switches. Two incandescent lamps, of the machine voltage, are cross-connected as shown. If the machines are in phase and the voltages generated are equal in value, the difference of potential between A and a given point is the same as that between A' and the same point; likewise B and B' have the same relative potential values. Hence a lamp connected between A and B' would burn with the same brilliancy as if it were connected directly across AB; likewise with the other lamp. If, however, the machines happen to be directly opposite in phase but to be generating voltage of the same value, A and B' are of the same relative potential value, and B and

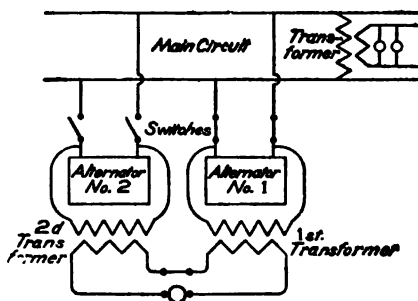


Fig. 23.

A' are likewise of the same value; hence lamps cross-connected as in Fig. 22 would be dark. At any other phase difference the lamps will glow, but not so brightly as when in phase. Hence, with this arrangement, the machines should be thrown in parallel when the lamps are on the verge of maximum brightness, a condition readily determined, but not possible with the first method.

The connections as shown in Figs. 21 and 22 are not directly applicable to high-tension working, but require the introduc-

tion of transformers as shown in Fig. 23, which is a modification of Fig. 22. The secondaries (of, say, 50 volts each) should be connected in series with each other and to one 100-volt lamp. When the two machines are opposed in phase, the lamp is dim. If the lamp flickers badly, the phase is not right; but if the lamp is steady at full brightness, the machines are in phase, and they may be connected without disturbing the circuit, by closing the main switch.

If alternators are rigidly connected to each other or to the engine, so that they necessarily run exactly together, there is no need of bringing them into step each time, but they should be adjusted to the same phase in the first place.

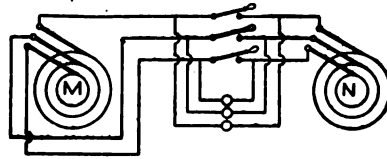


Fig. 24.

The connections of the synchronizing lamps of a three-phase system are similar to those for a single-phase system. For instance, the method employed in Fig. 21 may be extended, and lamps connected as in Fig. 24. If the three lamps simultaneously become dark or bright, the connections are correct, and the three switches may be closed at an instant of darkness. It may happen, however, that the lamps do not become bright or dark simultaneously but successively. This indicates that the order of connection of the leads of one machine does not correspond with that of the other. In this case, transpose the leads of one machine until the proper or simultaneous action of the lamps is obtained. After the machines have been

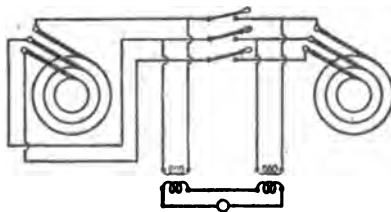


Fig. 25.

properly connected, it is sufficient to synchronize with one of the lamps. Similarly, with high-tension systems, only a single-phase transformer is required, connected as shown in Fig. 25.

Generators in Series. This arrangement is less common

than parallel working, and does not usually operate so well, except with series-wound machines on arc circuits, which is very

successful. The conditions are exactly opposite to those in the preceding group—generators in parallel.

To connect machines in series, the positive terminal of one must of course be connected to the negative terminal of the next, and so on. Each must have a current capacity equal to the maximum current on the circuit, but they may differ to any extent in E. M. F. The voltages of machines in series are added together; and therefore danger to persons, insulation, etc., is increased in proportion.

Series-Wound Direct-Current Dynamos in Series are connected in the simple way represented in Fig. 26; but, usually machines connected in series are for arc lighting—for example, when two dynamos, each of 40 lights capacity, are run on one circuit of 80 lamps, in which case the dynamos usually have some

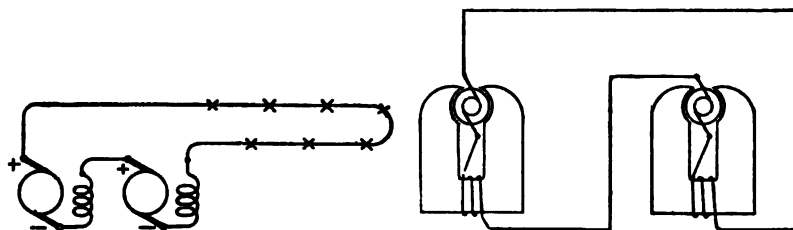


Fig. 26.

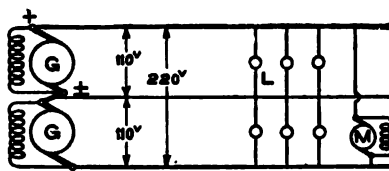
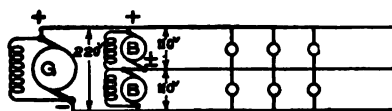
form of regulator. These regulators do not usually work well together, because they are apt to "seesaw" with each other. This difficulty may be overcome either by connecting the regulators so that they work together, or by setting one regulator to give full E. M. F. and letting the other alone control the current. This latter plan can be followed only when the variation in load does not exceed the power of one machine. Constant-current dynamos having regulators with little inertia in the moving parts, and thus little tendency to "overshoot," such as the Brush machine, can be run in series without much trouble.

Shunt or Compound Dynamos in Series run well, provided the shunt-field coils are connected together to form one shunt across both machines. If the machines are compound, all of the series coils must be connected in series with the main circuit. Another plan is to connect each shunt field so that it is fed only

by the armature of the other machine ; or both the shunt coils may be connected so as to be fed by one armature, the series coils being in the main circuit as before.

Alternators in Series. The synchronizing tendency which makes it possible to run alternators in parallel, causes them to get out of step and become opposed to each other when it is attempted to run them in series. It is therefore impracticable to run them in series unless their shafts are rigidly connected so that they must run exactly in phase and thus add their waves of current instead of counteracting each other. This case rarely occurs.

Dynamos on the Three-Wire System (Direct-Current). In the ordinary three-wire system for incandescent lighting and power service, no particular precautions are required in starting or connecting the machines; and either of the two arrangements shown in Figs. 27*a* and 27*b* may be adopted. The two sides of the

Fig. 27*a*.Fig. 27*b*.

system are almost independent of each other, and form practically separate circuits, for which the middle or neutral wire acts as a common conductor. There is, however, a tendency for the dynamos (Fig. 27*a*) to be reversed in starting up, in shutting down, or in the case of a severe short circuit. This can be avoided by exciting the field coils of all the dynamos from one side of the system, or from a separate source. To obtain good regulation, it is necessary to balance the load equally on both sides of the system. It is advisable to employ 220-volt motors on 110-volt 3-wire systems, and to connect them across the outside conductors so that the motor load shall not unbalance the system.

KINDS OF MOTORS, CONNECTIONS, AND STARTING.

The general instructions relating to the adjustment of brushes, screws, belt, oil-cups, etc., given in relation to the generator, should be carefully followed preparatory to starting a motor. The actual

starting of a motor is usually a simple matter, since it consists merely in operating a switch; but in each case there are one or more important points to be considered

CONSTANT-POTENTIAL D. C. CIRCUITS.

Shunt-Wound Motor. A motor to operate at nearly constant speed, with varying loads, on a D. C. constant-potential system (110- or 220-volt lighting circuits) is usually plain shunt-wound. This is the commonest form of stationary motor. The field coils are wound with wire of such a size as to have the proper resistance and resulting magnetizing current; and since the potential applied is practically constant, the field strength is constant.

In starting shunt motors, no trouble is likely to occur in connecting the field to the circuit. The difficulty is with the armature current, because the resistance of the armature is very low in order to get higher efficiency and constancy of speed, and the rush of current through it in starting might be twenty or more times the normal number of amperes. To avoid this excessive current, motors are started on constant-potential circuits through a rheostat or "starting-box" containing resistance coils.

The main wires are connected through a branch cut-out (with safety fuses), and preferably also a double-pole knife switch *Q*, to the motor and box, as indicated in Fig. 28. When the switch *Q* is closed, the arm *S* being in its left-hand position, the field circuit is closed through the contact stud *f*, and the armature circuit is closed through the resistance coils *a, a, a*, which prevent the rush of current referred to. The motor then starts, and as the speed rises it generates a counter E. M. F., so that the arm *S* can be turned as shown until all the resistance-coils *a, a, a*, are cut out, and the motor is directly connected to the circuit and running at full speed. The arm *S* should be turned slowly enough to allow the speed and counter E. M. F. to come up as the resistances *a, a, a* are cut out. The arm *S* should positively close the field circuit first, so that the magnetism reaches its full strength (which may take several seconds) before the armature is connected.

In the arrangement shown in Fig. 28 the release magnet has its coils in series with the field. As long as the motor is in operation, the core is energized and the arm *S* is held in the posi-

tion shown. If, however, the current supplied to the motor is cut off and the motor comes to rest, the core of the magnet loses its attractive force, and the arm S is released, being automatically moved back to the starting position by a spring.

The coils a, a, a are made of comparatively fine wire, which can carry the current only for a few seconds in a "starting-box;"

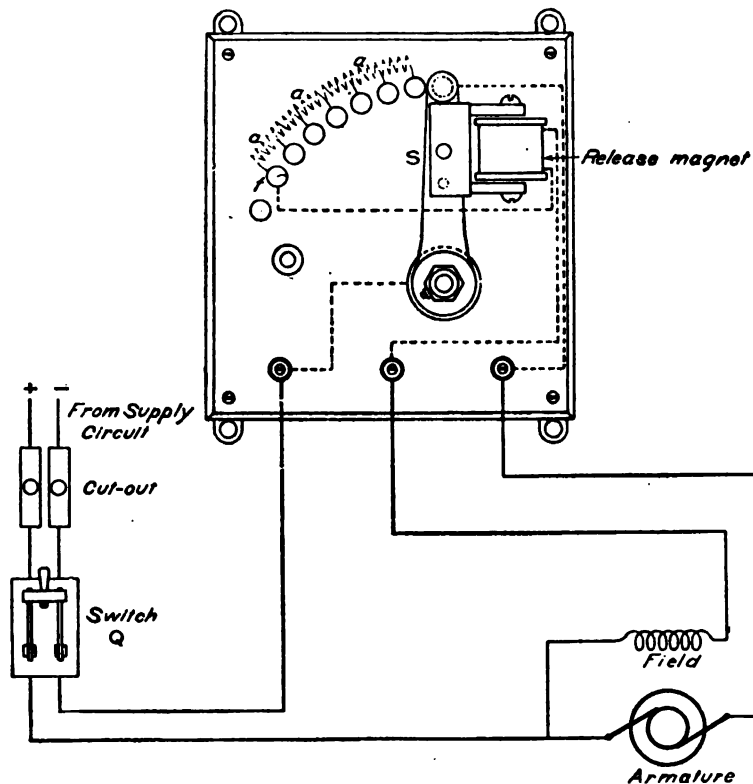


Fig. 28.

but if the wire is large enough to carry the full current continuously, it is called a "regulator," because the arm S may be left so that some of the resistances a, a, a remain in circuit, and they will have the effect of reducing the speed of the motor, which is often very desirable.

In some cases where a circuit is used exclusively for a single motor, the speed is regulated without heavy resistances by varying

the E. M. F. of the dynamo which supplies the circuit. The dynamo regulator is then placed near the motor. The advantage is that the regulator is not compelled to control a heavy current, but a special circuit of unvaried pressure must be provided to keep the field of the motor constant.

The speed control of a shunt motor may be simply obtained as follows:

a. For lower speeds, insert resistance in series with the armature circuit. The resulting I. R. drop reduces the value of the voltage applied to the armature terminals, and thus reduces the speed.

b. For higher speeds, insert resistance in the shunt-field circuit. This reduces the magnetic flux, and to generate the same C. E. M. F. the motor must speed up.

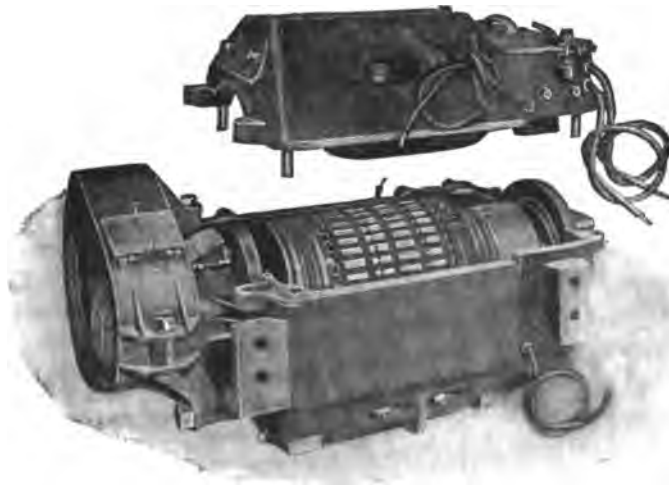


Fig. 29.

The field circuit of a shunt motor should never be opened while pressure is still applied to the armature terminals, as under these conditions the armature current becomes very excessive and the armature is likely to race and probably be damaged. A moderate decrease in field strength only is allowable; otherwise sparking becomes excessive.

Series-Wound Motor. The ordinary electric railway motor on the 550-volt trolley system is the chief example of the class (Fig. 29.) Motors for fans, pumps, or electric elevators and hoists

are either of this kind or of the compound type. A rush of current tends to occur when the series type of motor is started, similar to that in the case just described ; but it is less, because the field-coils are in series, so that their resistance and self induction reduce the excess. Furthermore, the counter E. M. F. is greater even at low speed because the heavy current produces a strong field.

The connections as indicated in Fig. 30 are very simple, the armature, field-coils, and rheostat all being in series and carrying the same current.

The series-wound motor on a constant-potential circuit does not have a constant field strength, and does not tend to run at con-

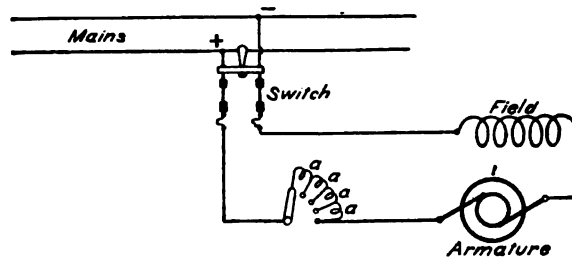


Fig. 30.

stant speed, like a shunt motor. In fact it may "race" and tear itself apart if the load is taken off entirely; it is therefore suited only to railway, pump, fan, or other work where variable speed is desired, or where there is no danger of the load being removed or a belt slipping off. It is also used where the potential is subject to sudden and large drops, as on the ends of long trolley circuits, because in such a case a shunt motor becomes momentarily a generator and sparks very badly. The fields of series motors are sometimes "overwound," that is, so wound that they will have their full strength with even one-half or one-third of the normal current. The objects are to secure a nearly constant speed with varying loads, to enable the motor to run at high efficiency when drawing small currents, and to prevent sparking at heavy loads.

In multipolar motors having more than two field-coils, the coils are all connected together, and are equivalent to the single pairs of coils shown in the several diagrams. Being separated,

however, it is sometimes necessary to trace out the connections. Fig. 31 represents the necessary connections for a four-pole motor, shunt-wound and series-wound.

Differentially-Wound Motor. This is a shunt-wound motor with the addition of a coil of large wire, on the field, connected in series with the armature in such a way as to oppose the magnetizing effect of the shunt winding and weaken the field, thus causing the motor to speed up when the load is increased, as an offset to the slowing-down effect of load.

It was formerly used, for obtaining very constant speed, but it has been found that a plain shunt motor is sufficiently constant for almost all cases. The differential motor, if overloaded, has

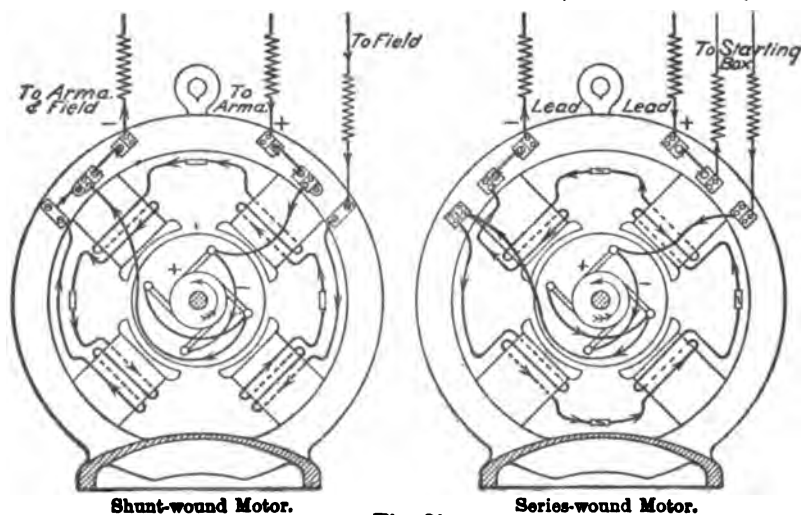


Fig. 31.

the great disadvantage that the current in the opposing (series) field-coil becomes so great as to kill the field magnetism; and instead of increasing or keeping up its speed, the armature slows down or stops, and is likely to burn out; whereas a plain shunt motor can increase its power greatly for a minute or so when overloaded, and will probably throw off the belt or carry the load until the latter decreases to the normal amount.

Compound-Wound Motor. This type of motor is also provided with a shunt and a series-field winding, Fig. 32, but in this instance they magnetize the field in the same direction, or, in other



TWO FORT WAYNE TWO-PHASE ALTERNATORS
Revolving Field. Engine Driven.

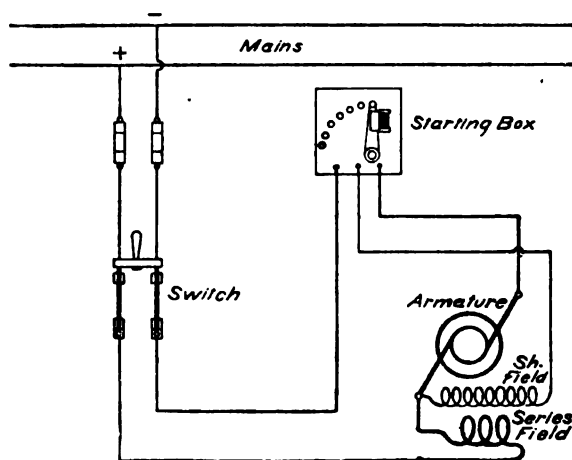


Fig. 32.

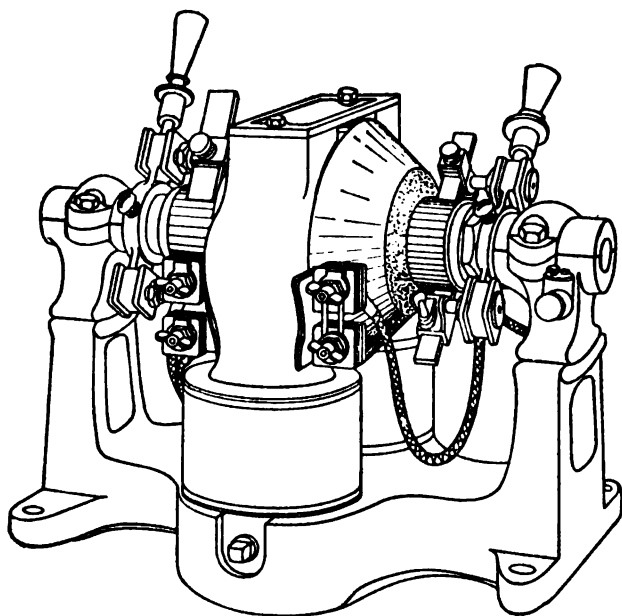


Fig. 33.

words, their effect is cumulative. This type of motor possesses the powerful starting torque feature of the series motor, but a less variable speed with varying loads. It is employed where a great starting torque and a fairly uniform running speed are required, as, for example, with electric hoists or elevators.

Dynamotors, Fig. 33, and also motor-generator sets, are started in the same way as motors; that is, the motor portion of the machine is connected to the circuit and operated precisely like the corresponding kind of motor. Usually the motor part is plain shunt-wound, and is supplied with current from a constant-potential circuit. It is therefore connected and started in the manner shown and described on page 40.

The current generated by the dynamo portion of the dynamotor may be taken from the terminals, and used for any purpose to which it is suited. The E. M. F. or current produced may be regulated by varying the resistance in the armature circuit of either the motor or dynamo. In case the dynamo armature has a separate field magnet, the E. M. F. and current may be controlled by regulating the magnetic strength of this field, or the machine may be compounded or even "over-compounded." But if the armatures of both motor and dynamo are acted upon by the same field, the E. M. F. of the dynamo cannot be varied except by inserting resistances in the circuit of either armature or by shifting the brushes. But the latter method will be likely to cause sparking.

ALTERNATING-CURRENT MOTORS.

Alternating-current motors operate on constant-potential circuits, since almost all A. C. systems are of this kind. There are several types of these motors, the simplest of which is the *series machine* for single-phase current. This is similar to the corresponding D. C. motor, except that its field must be laminated.

It possesses the characteristic of large starting torque and lends itself to variable speed control like its direct current counterpart and is coming into use very rapidly for electric railway work. Both the General Electric and the Westinghouse Electric and Manufacturing Companies have placed such machines upon the market and they are already in operation on a number of electric roads where they are giving satisfaction.

This type of motor while retaining practically all the advantages of the direct-current series motor for electric railway work permits the use of alternating current on the trolley with all its attendant advantages. A frequency of 25 seems likely to become the standard for such work. The cars can be operated on existing

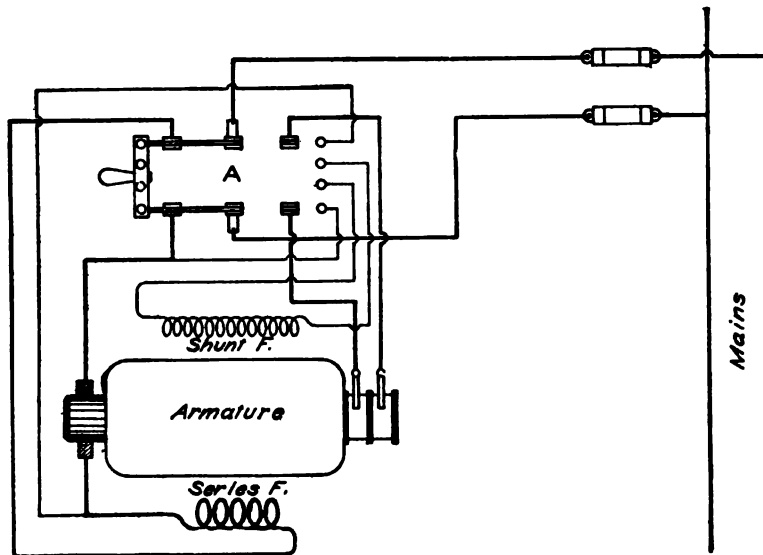


Fig. 34.

direct-current lines and the multiple unit control system can be applied to cars equipped with single-phase motors.

An ordinary single-phase alternator can be used as a motor; but it must first be brought up to synchronism with the supply generator by means of some auxiliary starting device (steam engine, polyphase induction motor, etc.) before the load can be applied. In this form the machine is known as the *single-phase synchronous motor*. The condition of synchronism is determined by one of the methods described in the paragraph on "Alternators in Parallel." After the motor is in synchronism it may be connected to the circuit by closing its supply switch; and it will then continue to run at an absolutely constant speed, unless heavily overloaded, when it falls out of step and stops.

On account of these features, the synchronous motor is not to

be recommended for general application. Various manufacturers, notably the Wagner Electric Company, and the Fort Wayne Electric Company, manufacture self-starting, single-phase synchronous motors, usually limited, however, to the smaller sizes. The construction and action of the Fort Wayne motor (Fig. 34), which is a combination of the two preceding types, are as follows: The armature core is provided with a double winding, one equipped with collecting rings, and the other with an ordinary commutator. The field magnet, which is laminated, is wound with two separate circuits, one being of low resistance and a small number of turns, the other of high resistance and many turns, like an ordinary shunt-field winding. In starting, the motor runs as a



Fig. 35.

series machine, the low-resistance field being in series with the commutated armature winding and the line. When it has reached synchronism, the switch A, on the top, is thrown over to the right, and the supply line connected with the collector rings and the corresponding armature winding; while the commutated end is connected to the other field winding, and thus

provides the direct current necessary for field excitation.

In addition to the single-phase there is also the *polyphase synchronous motor*. This latter form, however, is self-starting without field current, but will not carry a load until it is running in synchronism. When this condition is reached, the field circuit should be closed before applying the load.

A great advantage of the synchronous motor is that when its field is over-excited, it draws a leading current from the line, thus acting like a condenser and tending to neutralize the inductive effect of other machinery, so that the power factor of the whole system is raised. The most extensive use of the synchronous motor is as a part of the rotary converter, which is employed to convert alternating into direct currents, for traction and electro-chemical purposes.

The satisfactory use of alternating currents for power purposes depends mainly on the *polyphase induction motor*, as in this form the A. C. motor is self-starting with considerable torque and operates at a practically constant speed from no load to a heavy overload. Induction motors are designed for the standard voltages and frequencies.

In most induction motors now built, the primary, or part into which the currents from the line are led, is the stationary member, or *stator*. The secondary, in which the induced currents are set up, is the rotating member, or *rotor*. There are two kinds of rotor



Fig. 36.

windings, the simpler being that known as the "squirrel-cage." This winding is made up of a number of copper bars, equally spaced around the rotor core, and imbedded therein. The terminals of these inductors are interconnected, or short-circuited, by means of heavy copper rings placed at both ends of the core, as shown in Fig. 35.

The other form of winding is of the drum species, usually three-phase, Y-connected; and the coils are located at 120° intervals (the arc between centers of adjacent poles being called 180°) with respect to each other. The free ends of the windings are respectively brought out to three slip or collecting rings; and on this account this type of rotor is frequently called the "slip-ring" rotor (Fig. 36).

Starting Induction Motors. In small sizes, up to 3 or 5 H. P., the induction motor can be started by connecting its stator terminals directly to the line. But with larger sizes the inrush

of current is excessive and likely to disturb the system; accordingly some form of starting device is usually necessary.*

Starting Compensators. This inrush of current can be avoided by inserting a starting resistance, or inductance, in series with the primary winding and the line, or by using some other means of cutting down the applied E. M. F. The torque of an induction motor decreases as the square of the applied voltage, so that this method of starting results in a greatly reduced starting effort. However, in many instances, motors are not started up under full load, so that this may not be a serious objection.

While a resistance could be employed as described, it is more economical to employ an auto-transformer (that is, a transformer

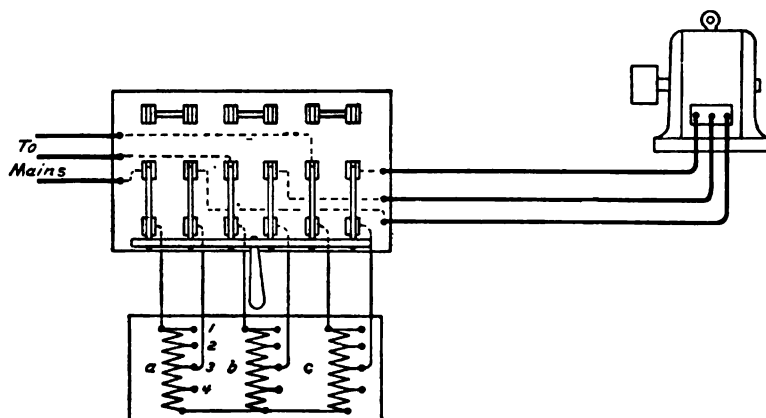


Fig. 37.

having but one coil, which serves as both a primary and a secondary), or *compensator*, as it is called when used for this purpose. Compensator connections for a three-phase motor are represented in Fig. 37. The compensator consists of coils *a*, *b*, and *c*, wound on a laminated-iron core, each coil being provided with a number of taps, 1, 2, 3, etc. The pressure applied to the motor at starting is proportioned to the amount of each coil included in the circuit. While the compensator winding is provided with taps, only that one which is most suitable for the work is used after the equipment is permanently installed. When the switch is in the

* This inrush of current is frequently three times the rated load current.

lower position as indicated, a part of each coil is in series with each leg of the system leading to the motor; and the applied voltage is correspondingly cut down. After the motor reaches its rated speed, the switch is thrown to the upper or running position, and the stator or primary terminals are connected directly to the line. The compensator thus prevents an excessive inrush of current, and gives the motor a smooth start, although it decreases the starting torque, compared with that due to full line pressure.

Speed Regulation of Induction Motors. For some classes of work, it is desirable to have induction motors arranged so that their speed can be controlled, the usual methods being :

- a. The insertion of a variable resistance in the rotor circuit.
- b. Cutting down the voltage applied to the stator, as just described.

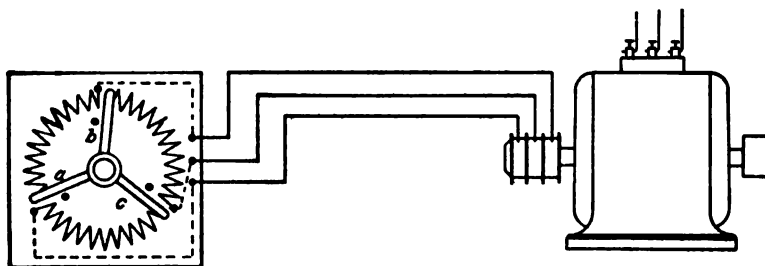


Fig. 38.

The more satisfactory method of speed control, is that with variable resistance inserted in the rotor circuit, the power-factor and hence the efficiency of the system being greater at reduced speeds than with the compensator or equivalent device. It requires, however, the use of collector rings, connecting brushes, and leads, since a resistance for continuous service is too bulky to be placed within the machine. Still further, the heat developed in the resistance would heat the machine too much. The controller itself looks like an ordinary trolley car controller, but for simplicity it is represented as a three-armed controller (Fig. 38) in which the arms *a*, *b*, and *c* are in electrical contact under the handle. The resistance is provided in three sets, one for each free end of the rotor winding; and each set is subdivided so that it can be gradually cut out of circuit as the motor speed increases. Frequently the controller is so arranged that the first motion of the handle

closes the supply lines, and subsequent motions vary the resistances in the rotor circuit, thus performing the function of a supply switch and speed controller.

Another method of speed control, is to have the winding on the stator arranged so that by means of a suitable controlling switch, the number of poles can be changed. This is a very economical method from the electrical standpoint, and gives a very wide range of control, but, on account of its complexity and cost, is used only to a limited extent.

In general, the induction motor does not allow of the same range of speed control as does the direct-current motor, and the methods employed for this purpose are not efficient.

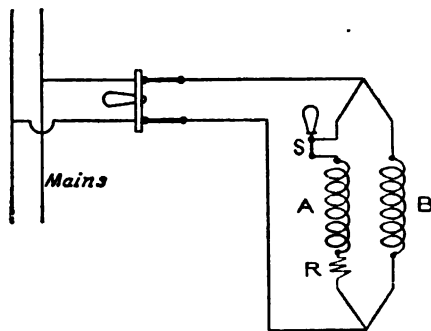


Fig. 39.

Single-Phase Induction

Motor. A two or three-phase induction motor will operate fairly well, if, after reaching full speed, all but one of the phases be cut out. It will not however start from rest under the influence of single-phase excitation. Hence, to start an induction motor from the lines of a single-phase system, currents differing in

phase must be obtained. This is accomplished by connecting the two primary windings A and B (in the case of a two-phase motor) in parallel to the single-phase mains, at the same time connecting in series with one winding a resistance R (Fig. 39). The currents flowing through these two windings will then differ in phase, one leading the other on account of a difference in their constants, and will thus produce a rotating field, and the motor will then start up.* When the motor has reached full speed, one phase may be cut out by opening the switch at S, and the machine will carry its load. The resistance R may be replaced to advantage by a condenser, especially on small machines. Such a machine is commonly called a "split-phase" motor.

* This field is not a rotary field in the full sense, being elliptical in character.

DIRECTIONS FOR RUNNING GENERATORS AND MOTORS.

After any one of these machines has been properly started, it usually requires little attention while running; in fact, generators or motors frequently operate all day without any care whatever.

In the case of a machine that has not been run before or has been changed in any way, it is wise to watch it closely at first. It is also well to give the bearings of a new machine plenty of oil at first, but not enough to run on the armature, commutator, or any part that would be injured by it; and to run the belt (if used) rather slack until the bearings and belt are in easy working condition.

If possible, a new machine should be run without load or with a light one for an hour or two, or for several hours in case of a large machine; and it is bad practice to start a new machine with its full load or even a large fraction of it. This is true even if the machine has been fully tested by its manufacturer and is in perfect condition, because there may be some fault in setting it up or some other circumstance that would cause trouble. All machinery requires some adjustment and care for a certain time to get it into smooth working order.

When this condition is reached the only attention required is to supply oil when needed, keep the machine clean, and see that it is not overloaded. A generator requires that its voltage or current should be observed and regulated if it varies. The attendant should always be ready and sure to detect the beginning of any trouble, such as sparking, heating, noise, abnormally high or low speed, etc., before any injury is caused, and to overcome it. Such directions should be pretty thoroughly committed to memory in order promptly to detect and remedy any trouble when it occurs suddenly, as is usually the case. If possible, the machine should be shut down instantly when any indication of trouble appears, in order to avoid injury and give time for examination.

Keep all tools or pieces of iron or steel away from the machine while running, as they might be drawn in by the magnetism, perhaps getting between the armature and pole pieces and ruining the machine. For this reason use a zinc, brass, or copper oil-can instead of one of iron or "tin" (tinned iron)

Particular attention and care should be given to the commutator and brushes, to see that the former keeps perfectly smooth and that the latter are in proper adjustment. (See "Sparking.")

Never lift a brush while the machine is delivering current unless there are one or more other brushes on the same side to carry the current, as the spark might make a bad burnt spot on the commutator, or might burn the hand.

Touch the bearings and field coils occasionally to see whether or not they are hot. To determine whether the armature is running hot, place the hand in the current of air thrown out from it by centrifugal force.

Special care should be observed by any one who runs a generator or motor, to *avoid overloading* it, because this is the cause of most of the troubles which occur.

Personal Safety. Never allow the body to form part of a circuit. While handling a conductor, a second contact may be made accidentally through the feet, hands, knees, or other part of the body, in some peculiar and unexpected manner. For example, men have been killed because they touched a "live" wire while standing or sitting upon a conducting body.

Rubber gloves or rubber shoes, or both, should be used in handling circuits of over 500 volts.* The safest plan is not to touch any conductor while the current is on; and it should be remembered that the current may be present when not expected, owing to an accidental contact with some other wire or to a change of connections. Tools with insulated handles, or a dry stick of wood, should be used instead of the bare hand.

The rule to use *only one hand* when handling dangerous electrical conductors or apparatus is a very good one, because it avoids the chance, which is very great, of making contacts with both hands and getting the current through the body. This rule is often made still more definite by saying, "Keep one hand in your pocket," in order to make sure not to use it. The above precautions are often totally disregarded, particularly by those who have become careless through familiarity with dangerous currents. The result has been that *almost all persons accidentally killed*

* These articles should be subjected to tests at frequent intervals, ~~so~~ as to determine their condition.

by artificial electricity have been experienced linemen or station men.

Stopping Generators or Motors. This is accomplished by following substantially the same directions as for starting them, but in the reverse order.

A generator operating alone on a circuit can be slowed down and stopped without touching the switches, brushes, etc., in which case the current gradually decreases to zero; and then the connections can be opened without sparking or any other difficulty.

However, when a generator is operating in parallel with others, or with a storage battery, it must not be stopped or reduced in speed, until it is entirely disconnected from the system, otherwise it will act as a short circuit. Furthermore, the current generated by it should be reduced nearly to zero before its switch is opened. This is accomplished by adjusting the field rheostat of the machine to be cut out, great care being taken that the change is gradual. If the reduction be rapid, the voltage of the machine may drop so low as to cause a back current to flow.

A **constant-current generator** may be cut into or out of circuit in series with others, and can be slowed down or stopped; or its armature or field coils may be short-circuited to prevent the action of the machine, without disconnecting it from the circuit. *It is absolutely necessary, however, to preserve the continuity of the circuit, and not to attempt to open it at any point, as this would produce a dangerous arc.* Hence a by-path must be provided by closing the main circuit around the generator, before disconnecting it. This same rule applies to any lamp, motor, or other device on a constant-current system.

Never, except in an emergency, should any circuit be opened when heavily loaded, for the reason that the flash at the contact points, discharge of magnetism, and mechanical shock which result, are decidedly objectionable.

A **Constant-Potential Motor** is stopped by turning the starting-box handle back to the position it had before starting (Fig. 28); or, *if there is a switch Q, connecting the motor to the circuit,* as there always should be, it should be opened, after which the starting-box handle is moved back to be ready for starting again.

Immediately after a machine is stopped, it should be thoroughly cleaned, and put in condition for the next run. When not in use, machines should, when feasible, be protected from dirt and moisture by covers of some waterproof material.

INSPECTING AND TESTING.

Adjustment and the other points which depend merely upon mechanical construction, are hardly capable of being investigated by a regular quantitative test, but they can and should be determined by thorough inspection. In fact a very careful examination of all parts of a machine should always precede any test of it. This should be done for two reasons: first, to get the machine into proper condition for a fair test; and, second, to determine whether the materials and workmanship are of the best quality and satisfactory in every respect. A loose screw or connection might interfere with a good test; and a poorly fitting bearing, brush-holder, or other part might show that the machine was badly made.

If it is necessary to take the machine apart for cleaning or inspection, the greatest care should be exercised in marking, numbering, and placing the parts, in order to be sure to get them together exactly the same as before. In taking a machine apart or putting it together, only the minimum force should be used. Much force usually means that something wrong is being done. A wooden or raw-hide mallet is preferable to an iron hammer, since it does not bruise or mar the parts. Usually screws, nuts, and other parts should be set up fairly tight, but not tight enough to run any risk of breaking or straining anything. Shaking or trying each screw or other part with a wrench or screw-driver, will show whether any of them are too loose or otherwise out of adjustment.

Friction. The friction of the bearings and brushes can be tested roughly by merely revolving the armature by hand, or slowly by power, and noting if it requires more than the normal amount of force. Excessive friction is quite easily distinguished, even by inexperienced persons. Another method is to revolve the armature by hand or otherwise, and see if it continues to revolve by itself freely for some time. A well-made machine in good condition and running at or near full speed, will continue to run for several minutes after the turning force is removed.

A method for actually measuring the friction consists in attaching a lever (a bar of wood, for example) to the shaft or pulley at right angles to it. The force required to overcome the friction and to turn the armature without current, is then determined by known weights or, more conveniently, by an ordinary spring balance. For convenience in dividing by the length of the lever, etc., to determine the value of the friction compared with the power of the machine, it should be exactly 1, 2, or 4 feet long. The friction of the bearings alone—that is, the pull which is required to turn the armature when the brushes are lifted off the commutator—should not exceed about 2 per cent of the total torque or turning force of the machine at full load. When the brushes are in contact with the commutator with the usual pressure, the friction should not then exceed about 3 per cent; that is, the brushes themselves should not consume more than 1 per cent of the total turning force.

Another method of measuring the friction of a machine is to run it by another machine used as a motor, and determine the volts and amperes required, first, with brushes lifted off, and second, with brushes on the commutator with the usual pressure. The torque or force exerted by the driving machine is afterwards measured by a Prony brake in the manner described hereafter for testing torque, care being taken to make the Prony brake measurements at exactly the same volts and amperes as were required in the friction tests. In this way the torques exerted by the driving machine to overcome friction in each of the first two tests are determined; and these torques, compared with the total torque of the machine being tested, should give percentages not exceeding those stated above for maximum values of friction. The magnetic pull of the field on the armature may be very great if the latter is not exactly in the center of the space between the pole pieces. This would have the effect of increasing the friction of the shaft in the bearings when the field is magnetized. It occurs to a certain extent in all cases, but it should be corrected if it becomes excessive. This may be tested by turning the current into the fields, being sure to leave the armature disconnected, and then turning the shaft with the lever as before. The friction in this case should not be more than 2 to 4 per cent.

Tests for friction alone should be made at a low speed, because at high speeds the effects of Foucault currents and hysteresis enter and materially increase the apparent friction.

Balance. The perfection of balance of the armature or pulley can be roughly tested by simply running the machine at normal speed and noting if these parts cause any objectionable vibration. Of course, practically every machine produces perceptible vibration when running, but this should not amount to more than a very slight trembling. The balance of a machine can be definitely tested, and the extent of the vibration measured, by suspending the machine or by mounting it on wheels, and running it at full speed. In this case it is better to run the machine as a motor, even though it be actually a generator, in order to avoid the necessity of running it by a belt, which would cause vibration and interfere with the test. If, however, the use of a belt is unavoidable, it should be arranged to run vertically upward or downward so as not to produce any horizontal motion in addition to the vibration of the machine itself. Fig. 40 shows a machine hung up to be tested for balance, and run either as a motor or by the vertical belt indicated by the dotted lines. Any lack of balance will cause the machine to vibrate or swing horizontally, and this motion can be measured on a fixed scale.

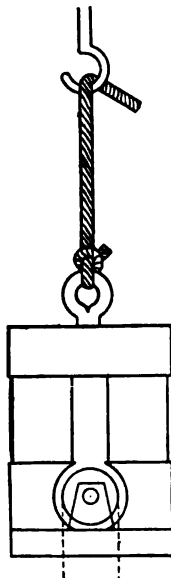


Fig. 40.

Noise. This cannot well be tested quantitatively, although it is very desirable that a machine should make as little noise as possible. Noise is produced by various causes. The machine should be run at full speed, and any noise and its cause carefully noted. A machine—especially the commutator—will nearly always run more quietly after it has been in use a week or more and has worn smooth.

Heating. The proper way to determine the temperature rise in electrical apparatus is by measurements of resistance, before and after operating for a specified time (usually 3 to 4 hours) under rated load.

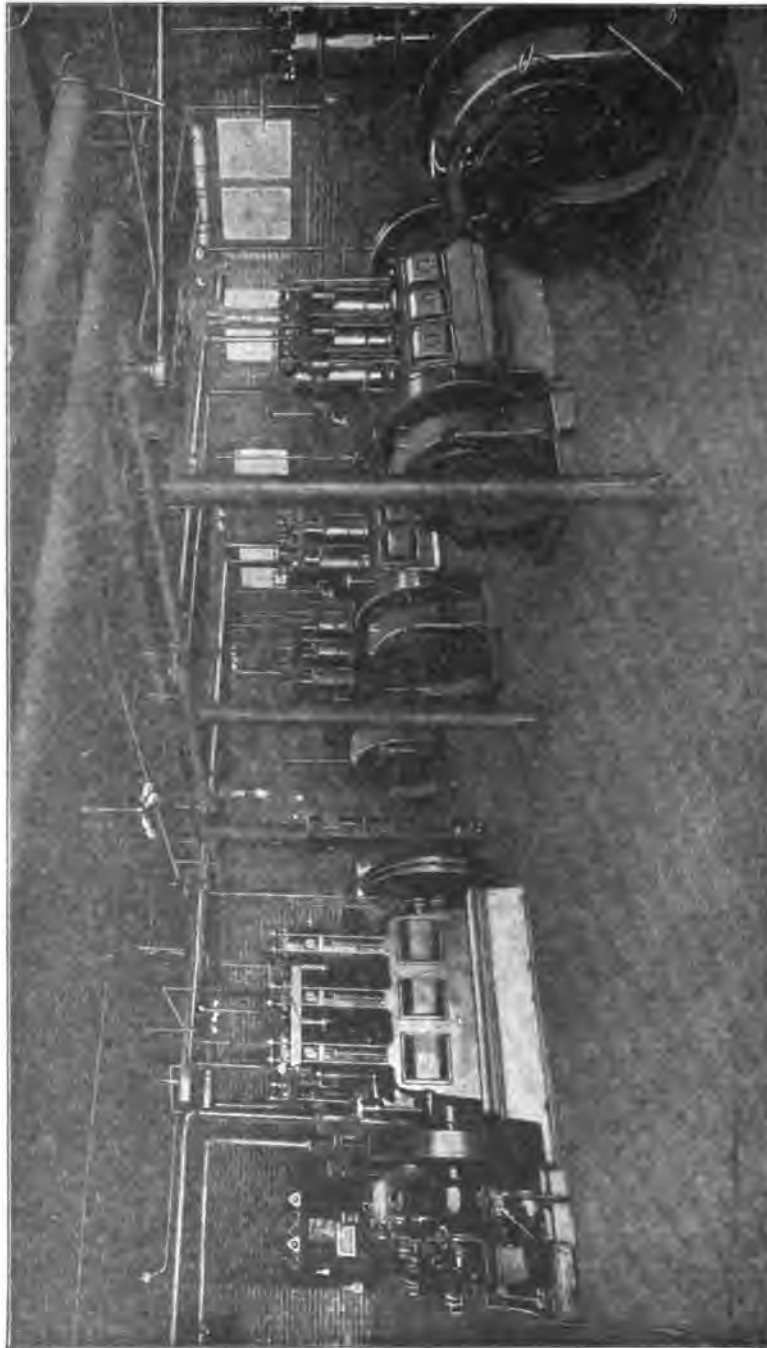
The rise of temperature is:

$$\theta = (238.1 + t) \left(\frac{R_t + \epsilon}{R_t} - 1 \right),$$

in which t is the room temperature in degrees Centigrade, R_t the resistance in ohms at room temperature, and $(R_t + \epsilon)$ the final resistance at a temperature elevation of θ° C. The standard room temperature is 25° C; and if it differs from this, the determined rise should be corrected by $\pm \frac{1}{2}$ per cent for each degree C. For ordinary tests it may be assumed that the resistance of copper increases .4 per cent for each degree C rise in temperature. The allowable rise in temperature for field or armature windings is 50° C, hence their resistance for continuous operation at rated load should not be more than 20 per cent in excess of the room temperature. The heating of commutators, collector rings, and brushes that cannot be measured electrically, is tested by thermometers when the machine is stopped, the permissible rise being 50° C; and for bearings and other parts of machines the limit is 40° C. When a thermometer is applied to a surface it should be covered by a pad of cotton or waste cloth, in a shallow, circular box about $1\frac{1}{2}$ inches in diameter. A large pad tends to accumulate heat. When machines are in operation, or in other cases when it is not convenient to measure resistances, especially for excessive temperatures due to abnormal conditions, thermometers may be used to test all stationary parts; but it should be noted that their indications are usually about 5° C lower than those determined by resistances, because the surface is cooler than the interior. A very simple test of heating is to apply the hand to the armature, etc., and if it can be held there without great discomfort, the temperature is not dangerous. Allowance should always be made, however, for the fact that, on account of its heat conductivity, bare metal feels very much hotter than cotton-covered wires, cloth, etc., at the same actual temperatures; but this apparent difference is much less if the hand is kept on for 10 to 20 seconds.

Sparking at the commutator cannot be accurately measured; but it is very objectionable, and in a machine in good order should be hardly perceptible. In any test one should observe carefully whether the sparking is excessive or not; and if so, to what it is due.

An approach to measurement may be made by starting with a lightly loaded machine and gradually increasing the load, meanwhile shifting the rocker-arm and brushes back and forth, and noting at what load it is impossible to find a non-sparking point. In machines the brushes must be shifted to follow the armature reaction as the load increases; but one should always be able to find a place where sparking ceases, within the rated load. In fact, a machine should be able to run with 25 per cent overload before sparking is serious. If a machine begins to spark at 50 per cent of its load, it is clearly only half as useful as it might be, and this may be taken in a sense as a measure of sparking.



WALRATH GAS ENGINES DIRECT CONNECTED TO GENERATORS
In Diamond Light & Power Company's Plant, Pittsburg

MANAGEMENT OF DYNAMO- ELECTRIC MACHINERY.

PART II

ELECTRICAL RESISTANCE.

Among the most important tests which it is necessary to make in connection with Dynamo-Electric Machinery are those for resistance.

There are two principal classes of resistance tests that must be made in connection with generators and motors. First, the resistance of the wires or conductors themselves, called the *metallic* resistance; and, second, the resistance of the insulation of the wires, known as the *insulation* resistance. The latter should always be as high as possible, because a low insulation resistance not only allows current to leak, but also causes "burn-outs" and other accidents. Metallic resistance, such, for example, as the resistance of the armature or field coils, is commonly tested either by the Wheatstone bridge or by the "drop" (fall-of-potential) method.

The Wheatstone Bridge is simply a number of branch circuits connected as indicated in Fig. 41.

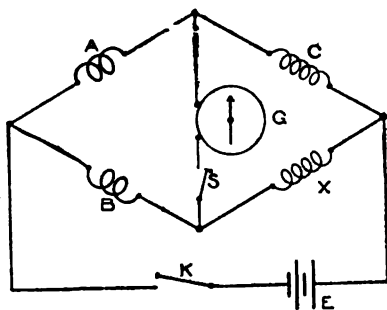


Fig. 41.

A, B, and C are resistances the values of which are known. X is the resistance which is being measured. G is a galvanometer, S its key, and E is a battery of one or two cells controlled by a key K, all being connected as shown. The resistance C is varied until the galvanometer shows no deflection,

when the keys K and S are closed in the order named. If the key S should be closed before K, or at the same moment, the

inductive effect would produce a pronounced deflection of the galvanometer needle, and thus probably cause confusion. The value of the resistance X is then found by multiplying together resistances C and B , and dividing by A ; that is,

$$X = \frac{C \times B}{A}.$$

A very convenient form of this apparatus is what is known as the portable bridge (Fig. 42). This consists of a box containing the three sets of known resistances, A , B , and C , controlled by plugs; also the galvanometer G , and keys K and S , all connected

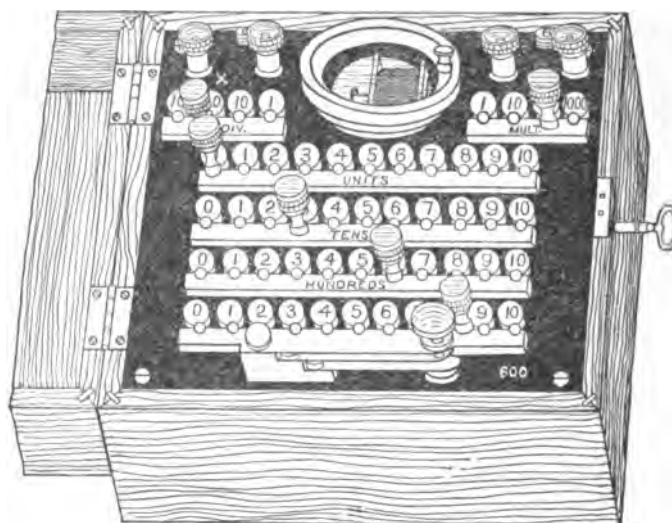


Fig. 42.

in the proper way. In some cases further convenience is secured by including the battery E in the box; but ordinarily this is not done, and it is necessary to connect one or two cells of battery to a pair of binding-posts placed on the box for that purpose. Resistances from $\frac{1}{10}$ ohm to 100,000 ohms can be conveniently and accurately measured by the Wheatstone bridge. Below $\frac{1}{10}$ ohm the resistances of the contacts in the binding-posts and plugs are apt to cause errors, and therefore special bridges provided with mercury contact cups are used. In fact, in measuring any resistance, care should be taken to make the connections clean and tight.

The ordinary bridge will not measure above 100,000 ohms, because, if the resistance in the arm B is 100 ohms, 1 ohm in A, and 1,000 ohms in C, then X is 100,000. Sometimes the arms A and B are provided with 1,000-ohm coils in addition to the usual 1-, 10- and 100-ohm coils; or sometimes the arm C contains more than 1,000 ohms in all; in either case the range will be correspondingly increased.

It should be observed, however, that the use of ratios of 1,000: 1, or even 100: 1, is not desirable, since they are likely to multiply any error due to contact resistances, etc. In fact, it is usually better to have the four resistances not very widely different in value; that is, no one of them should be more than ten times greater than any other except when very high or very low resistances are to be measured. The Wheatstone bridge may be used for testing the resistances of almost any field coils that are found in practice. Shunt fields for 110-volt machines usually vary from about 100 or 200 ohms in a 1-H. P. machine to about 5 to 20 ohms in a 100-H. P. machine. If the voltage is higher or lower than 110, these resistances vary as the square of the voltage. Series fields for arc-circuit dynamos vary from about 1 to 20 ohms. In measuring field resistances with the bridge, care must be taken to wait a considerable time after pressing the battery key, before pressing the galvanometer key, in order to allow time for the self-induction of the magnets to disappear.

The bridge may be used also for testing the armature resistance of some machines. But 110-volt shunt machines above 10 H. P. usually have resistances less than $\frac{1}{10}$ ohm, which is below the range of the ordinary bridge, as already stated. For higher or lower voltages the resistance is proportional to the square of the voltage. Arc machines have armatures of about 1 to 20 ohms resistance, and are therefore easily tested by the bridge.

The Drop (or Fall-of-Potential) Method is well adapted for locating faults quickly, and for testing the armature resistance of most generators and motors, or the resistance of contact between commutator and brushes, or other resistances which are usually only a few hundredths or even thousandths of an ohm. This consists in passing a current through the armature and connections and a known resistance (of, say, $\frac{1}{10}$ ohm), all connected in series,

as represented in Fig. 43. The "drop" or fall of potential in the armature and that in the known resistance are compared by connecting a voltmeter first to the terminals of the known resistance (marked 1 and 2), and then to various other points on the circuit, as indicated by the dotted voltmeter terminals at M, N, O, Q, R, and S, so as to include successively each part to be tested. The deflections in all cases are directly proportional to the resistances included between the points touched by the terminals. The current needed depends upon the resistance of the circuit and the sensitiveness of the voltmeter. A bank of lamps or a liquid resistance is used for limiting the current. Instead of using a

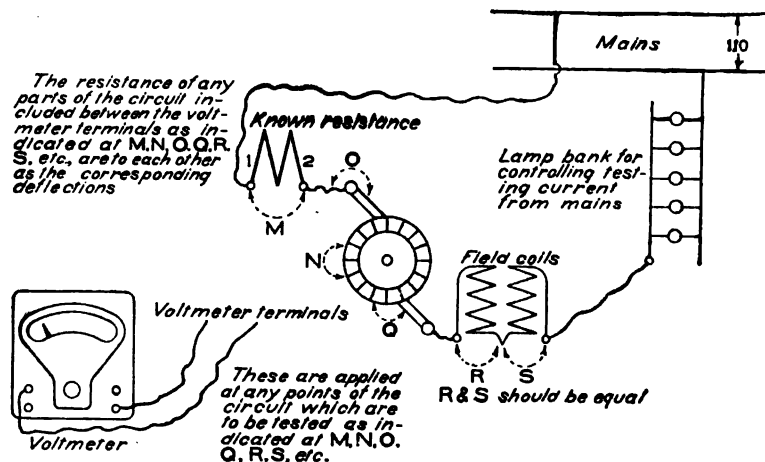


Fig. 43.

known resistance, an ammeter may be inserted in series with the resistance to be tested, the latter being then determined by Ohm's law, *viz.*, If E is the voltmeter deflection, and I represents the amperes flowing, the resistance of the part under test is $R = \frac{E}{I}$

A "station" or a portable voltmeter may be used for the readings, and its terminals may be held in the hands, or they may be conveniently arranged to project from an insulating handle like a two-pronged fork. Usually 10 to 100 amperes and a low-reading voltmeter are needed for low resistances.

It is well to start with a small testing current, and increase it until a good deflection is obtained on the voltmeter. If a current

of several amperes cannot be had, a few cells of storage battery or some strong primary battery, such as a Bunsen, bichromate, or plunge battery, can be used with a galvanometer or low-reading voltmeter.

The diagram indicates the testing of a machine with series fields. Shunt fields must be connected directly to the line on account of their high resistance; while the armature can be connected as here shown, without being allowed to revolve.

This drop method of testing is also very useful in locating any fault. The two wires leading from the voltmeter are applied to any two points of the circuit, as indicated by the dotted lines—for instance, to two adjacent commutator segments, or to a brush tip and the commutator; any break or poor contact will be

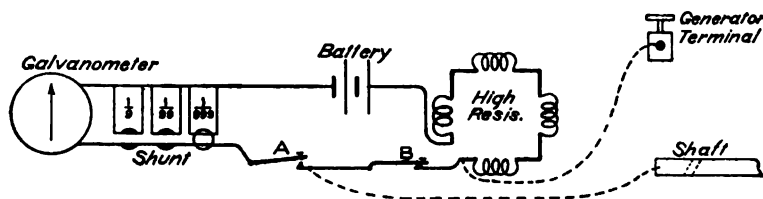


Fig. 44.

indicated immediately by the deflection being larger than at some other similar part. This shows that the fault is between the two points to which the wires are applied. Thus, by moving these along on the circuit, the exact location of any irregularity, such as a bad contact, short circuit, or extra resistance, can be found.

The *insulation resistance* of a generator or motor, that is, the resistance between its wires and its frame, should be sufficiently high so that not more than one-millionth of its rated current will pass through it at normal voltage, and it is well to have it still higher. It is therefore beyond the range of ordinary Wheatstone-bridge tests; but two good methods are applicable—the “direct-deflection” and the voltmeter method.

The Direct-Deflection Method is carried out by connecting a sensitive galvanometer, such as a Thomson high-resistance reflecting galvanometer, in series with a known high resistance, usually a 100,000-ohm rheostat, a battery, and keys, as shown in Fig. 44. The galvanometer should be shunted with the $\frac{1}{25}$ coil of the

shunt, so that only $\frac{1}{1000}$ of the current passes through the galvanometer, the machine being entirely disconnected. The keys A and B are closed and the steady deflection noted. It is well to use but one cell of the battery at first, and then increase the number if necessary until a considerable deflection is obtained. The circuit is then opened at the key B, and connected by wires to the binding-post or commutator and to the frame or shaft of the machine, as indicated by dotted lines, so that the machine insulation resistance is included directly in the circuit with the galvanometer and battery. The key A is then closed and the deflection noted. Probably there will be little or no deflection, on account of the high insulation resistance; and the shunt is changed to $\frac{1}{10}$, $\frac{1}{5}$, or left out entirely if little deflection is obtained. In changing the shunt, the key should always be open, otherwise the full current is thrown on the galvanometer. The insulation is then calculated by the formula:

$$\text{Insulation resistance} = \frac{D \times R \times S}{d},$$

in which D is the first deflection without the machine being connected, and d the deflection with the machine insulation in the circuit, R the known high resistance, and S the ratio of the shunt. That is, if the shunt is $\frac{1}{10}$ in the first test, and $\frac{1}{5}$ in the second, then S is 100; and if the shunt is out entirely in the second test, S is 1,000. It is safer to leave the high resistance in circuit in the second test, to protect the galvanometer in case the insulation resistance is low. Therefore this resistance must be subtracted from the result to obtain the insulation of the machine itself.

By the above method it is possible to measure 100 megohms or even more. The wires and connections should be carefully arranged to avoid any possibility of contact or leakage, which would spoil the test. If no deflection is obtained, place one finger on the frame and one on the binding-post of the machine, which makes enough leakage to affect the galvanometer and show that the connections are right, thus proving that any poor insulation will be indicated if it exists.

The Voltmeter Test for Insulation Resistance requires a sensitive high-resistance voltmeter, such as the Weston. Take, for example, the 150-volt instrument, Fig. 45, which usually has

about 15,000 ohms resistance. (A certificate of the exact resistance is pasted inside each case.) Apply it to some circuit or battery, and measure the voltage. This should be as high as possible—say, 100 volts. The insulation resistance of the machine is then connected into the circuit, as indicated in Fig. 46. The deflection of the voltmeter is less than before, in proportion to the value of the insulation resistance.

The insulation is then found by the equation :

$$\text{Insulation resistance} = \frac{D \times R}{d} - R,$$

in which D is the first and d

the second deflection, and R the resistance of the voltmeter. If the circuit is 100 volts, D is 100; and if d , the deflection through the insulation resistance of the machine, is 1 division, the insulation is 1,485,000 ohms. Permanent marks indicating amounts of insulation may be put on the voltmeter scale. When making measurements, the voltage should be the same as that employed in preparing this scale (say, 115 volts). To calculate the scale use this formula:

$$d = \frac{115 R}{X + R},$$

in which X is the insulation resistance (1 megohm, $\frac{1}{2}$ megohm, etc.), and d is the number of volts, opposite which the corresponding graduation is to be placed to form the new scale. This method does not test very high resistances; but if little or no deflection is obtained through the insulation resistance, it shows that the latter is at least several megohms—which is high enough for most practical purposes.

The ordinary magneto-electric bell may be used to test insulation by simply connecting one terminal to the binding-post of the machine, and the other to the frame or shaft.

A magneto bell is rated to ring from 10,000 to 30,000 ohms and if it does not ring, it shows that the insulation is more than

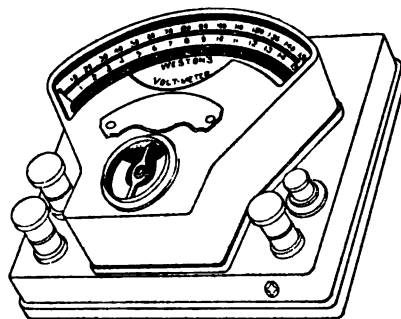


Fig. 45.

that amount. This limit is altogether too low for proper insulation in any case; and therefore this test is rough, and really shows only whether or not the insulation is very poor or the machine actually grounded.

The magneto is also used for "continuity" tests, to determine whether a circuit is complete, by simply connecting the two terminals of the magneto to those of the circuit. If the bell can be rung, it shows that the circuit is complete; if not, it indicates a break. An ordinary electric bell and cell of battery can be used in place of the magneto.

The insulation of a machine should always be tested for disruptive strength, with a current of at least double the normal working pressure, to see if it will "break down" or be punctured by the current. A transformer motor-dynamo wound to give high voltage is convenient for this.

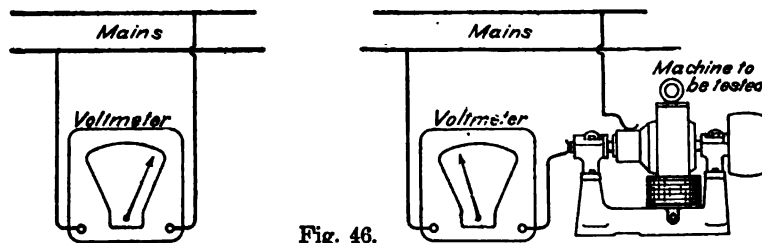


Fig. 46.

Tests of the resistances of generators or motors should properly be made when the machines are as warm as they get when running continuously at full load. This increases the resistance of conductors and decreases the insulation resistance, but it gives the actual working values.

Voltage. Instruments for measuring voltage (known as voltmeters) are in nearly all cases galvanometers of practically constant resistance. Through them flow currents which are directly proportional to the impressed voltages. A pointer connected to the moving part deflects over a graduated scale. A voltmeter should have as high a resistance as possible—at least several thousand ohms—in order not to take too much current, which might lower its reading on high-resistance circuit or consume too much power. It should not be affected by the magnetism of a generator or motor at any distance over a few feet.

The voltage of any machine or circuit is tested by merely connecting the two binding-posts or terminals of the voltmeter to the two terminals or conductors of the machine or circuit. To get the external voltage of a generator or motor, the voltmeter is usually applied to the two main binding-posts or brushes of the machine. This external voltage is what a generator supplies to the circuit. It is also called the pole difference of potential or terminal voltage, and is the actual figure upon which calculations of the efficiency, capacity, etc., of any machine are based.

A generator for constant-potential circuits should, of course, give as nearly as possible a constant voltage. A plain shunt machine usually falls from 5 to 15 per cent in voltage when its current is varied from nothing to full load. This is due to the $I R$ drop caused by the resistance of the armature circuit, which in turn weakens the field current and magnetism; armature reaction usually occurs also, and still further lowers the external voltage. This variation is undesirable, and is usually avoided by regulating the field magnetism (varying the resistance in the field circuit) or by the use of compound-wound generators. A compound-wound dynamo should not fall appreciably from no load to full load; in fact, if it is "over-compounded" it should rise 5 per cent or more in voltage to make up for loss on the wiring.

The voltage of a constant-current generator is not important. The current should be carefully measured by an ammeter, but little attention is paid to the voltage in practical working; in fact, it changes constantly with variations in the load. But it is necessary, of course, to measure it in making efficiency or other exact tests.

A simple and fairly accurate method of measuring voltage is by means of ordinary incandescent lamps. A little practice enables one to tell whether a lamp has its proper voltage and brightness. In this way it is easy to tell if the voltage is even one or two per cent above or below the normal point. Voltages less than the ordinary can be tested by using low-voltage lamps or by estimating the brightness of high-voltage lamps. For example, a lamp begins to show a very dull red at one-third and a bright red at one-half its full voltage. Voltages higher than that of one lamp can be tested by using lamps in series. Thus 1,000 volts can be measured by using 10 lamps in series, and so on.

Current. This is measured by an ammeter (Fig. 47), which is usually cheaper than a voltmeter because it contains a comparatively small amount of wire. In testing the current of a generator or motor, it is necessary only to connect an ammeter, of the proper range, in series with the machine to be tested, so that the whole current passes through the instrument or its shunt. To test the current in the armature or the field alone, the ammeter is connected in series with the particular part. To avoid mistakes in the case of a shunt-wound generator, it is well to open the external circuit entirely in testing the current used in the field

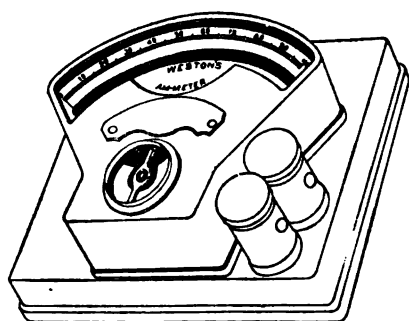


Fig. 47.

coils; for the same reason the brushes of a shunt motor should be raised before testing the current taken by the field.* In a constant-current or series-wound dynamo, the same current flows through all parts of the machine and the circuit; consequently the measurement of current is very simple.

If an ammeter cannot be had, current can be measured by

inserting a known resistance in the circuit and measuring the difference of potential between its ends. The volts thus indicated, divided by the resistance in ohms, gives the number of amperes flowing. If a known resistance is not at hand, the resistance of a part of the wire forming the circuit can be obtained from its diameter measured with a screw caliper or a wire gauge, by referring to any of the tables of resistances of wires; or the resistance can be measured by a Wheatstone bridge (Fig. 42), or by putting an ammeter, when one can be spared, into the circuit, while the voltmeter is connected. The volts divided by the amperes gives the resistance in ohms between the points to which the voltmeter is connected. Two connections can be attached permanently to two points on the circuit, and an ammeter tem-

* These instructions are to be followed when only one ammeter is to be had; otherwise one could be placed in the field circuit, and another in the circuit from the starting box to the independent armature terminal.

porarily inserted, and for every reading of the ammeter the corresponding reading of the voltmeter attached to these connections may be noted. Then, by keeping a list of these readings, the amperes can be found at any future time, by connecting the voltmeter to the two permanent contacts. This preliminary use of the ammeter amounts to measuring the resistance between the two contacts, and allows for the increase of resistance when the current and heating increase. In any case it is convenient to use a length of wire, or a distance between contacts, which will give an even amount of resistance, say, 1-10 or 1-100 ohm. And, as with large current the resistance will be fractional, care must be taken to avoid errors in multiplying, etc.

In testing the output of a generator, it is often quite a problem to dispose of the current produced. A bank of lamps, for



Fig. 48.

example, to use the whole current generated by a dynamo of 110 volts and 1,000 amperes, would be very expensive. A sufficient number of resistance-boxes for the purpose would also be very costly. The best way is to drive the generator by a motor, and connect it up in parallel with the line. In this way most of the power is returned instead of being wasted. If a motor cannot be had, the simplest and cheapest way to consume a large current is to place two plates of iron in a common tub or trough filled with a weak solution of carbonate of soda (common washing soda), which is better than almost any other solution because it neither gives off fumes nor eats the electrodes. The main conductors are connected to the two plates, respectively, and the current passes through the solution. The resistance and current are regulated by varying the distance between the plates, the depth they are immersed in the liquid, and the strength of the solution. The energy may be suf-

ficient to boil the liquid, but this does no harm. Three to ten amperes per square inch of active surface of plate may be allowed.

Speed. This is usually measured by the well-known **speed counter** (Fig. 48), consisting of a small spindle which turns a wheel one tooth each time it revolves. The point of the spindle is held against the center of the shaft of the generator or motor for a certain time, say, one minute or one-half minute, and the number of revolutions is read off from the position of the wheel.

Another instrument for testing the number of revolutions per minute is the **tachometer**. The stationary form of this instrument is shown in Fig. 49. It must be belted by a string, tape, or

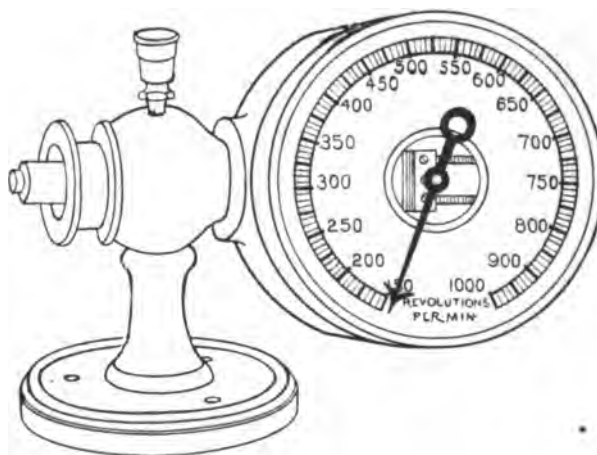


Fig. 49.

light leather belt to the machine the speed of which is to be tested. If the sizes of the pulleys are not the same, their speeds are inversely proportional to their diameters. The portable form of this instrument (Fig. 50) is applied directly to the end of the shaft of the machine, like the speed counter. The tip can be slipped upon either one of the three spindles, which are geared together, according as the speed is near 500, 1,000, or 2,000 revolutions. These instruments possess the great advantage over the speed counter that they instantly point on the dial to the proper speed, and they do not require to be timed for a certain period.

A simple way to test the speed in revolutions per minute is to make a large black or white mark on the belt of a machine, and

note how many times the mark passes per minute; the length of the belt divided by the circumference of the pulley gives the number of revolutions of the pulley for each time the mark passes. The number of revolutions of the pulley to one of the belt can also be easily determined by slowly turning the pulley or pulling the belt until the latter makes one complete trip around, at the same time counting the revolutions of the pulley. If the machine has no belt, it can be supplied with one temporarily for the purpose of the test, a piece of tape with a knot or an ink mark being sufficient. Care should be taken in all these tests of speed with belts not to allow any slip; for example, in the case of the tape belt just referred to, this belt should pass around the pulley

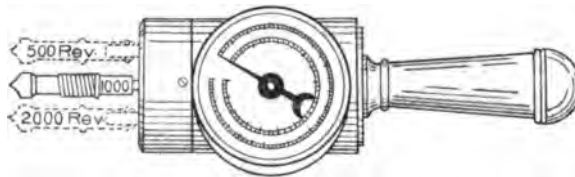


Fig. 50.

of the machine and some light wheel of wood or metal which turns so easily as not to cause any slip of the belt on the pulley of the machine.

Torque or Pull is measured in the case of a motor by the use of a Prony brake. This consists of a lever LL of wood, clamped on the pulley of the machine to be tested, as indicated in Fig 51. The pressure of the screws SS is then adjusted by the wing-nuts until the friction of the clamp on the pulley is sufficient to cause the motor to take a given current, and the speed is then noted. Usually, the maximum torque or pull is the most important to test; and this is obtained in the case of a constant-potential motor by tightening the screws SS until the motor draws its full current as indicated by an ammeter. What the full current should be, is usually marked on the name-plate; if not, it may be assumed to be about 8 amperes per H. P. for 110-volt motors, 4 amperes per H. P. for 220-volt, and 1 3-4 amperes per H. P. for 500-volt motors. If the machine is rated in kilowatts, the full current in amperes can be found by multiplying by 1,000 and dividing by the voltage of the machine. The torque or pull is measured by

known weights, or more conveniently by a spring balance P. If desired, the test may also be made at three-quarters, one-half, or any other fraction of the full current.

The torque or pull in pounds which should be obtained, can also be calculated from the power at which the machine is rated, by the formula ;

$$\text{Torque} = \frac{\text{H. P.} \times 33,000}{6.28 \times S},$$

in which H. P. is the horse-power of the machine at full load, and S is the speed of the machine in revolutions per minute at full load. Torque is given at unit radius, commonly pounds at one foot. The pull at any other radius is converted into torque by multiplying by the radius; 1, 2, and 4 ft. are convenient radii or lengths of lever for measuring pull. One H. P. produced at a speed of 1,000 revolutions requires a pull of 5.25 pounds at

end of 1-foot lever; at 500 revolutions, twice as much; at 2,000 revolutions half as much; and so on. If the lever is 4 feet, the pull is one-fourth as much, etc.

The Torque of a Generator, that is, the power required to drive it, is very conveniently determined by operating it as a motor, and testing it by the Prony brake as described above,

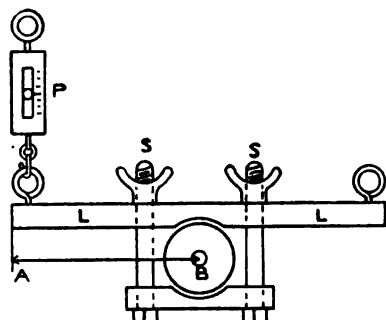


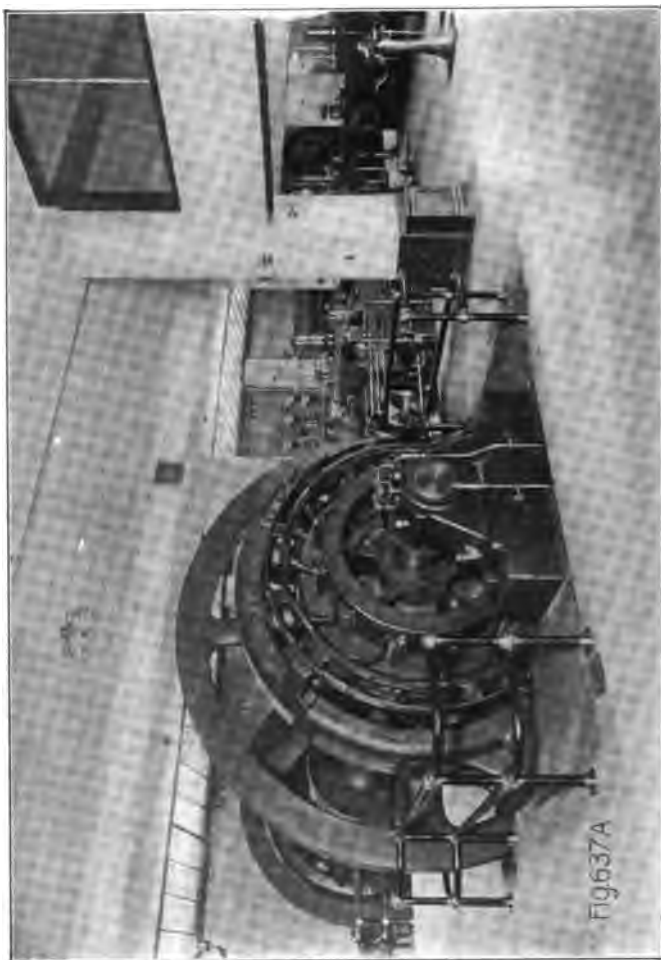
Fig. 51.

the torque of a generator being practically equal to that of a motor under similar conditions.

Power. The electrical power of a generator or motor is found by testing the voltage and current at the terminals of the machine, as already described, and multiplying the two together, which gives the electrical power of the machine in watts.* Watts are converted into horse-power by dividing by 746, and into kilowatts by dividing by 1,000.

The mechanical power of a generator or motor, that is, the

*In testing an alternating-current machine, a wattmeter should be employed instead of a voltmeter and an ammeter, as explained later.



400-K. W. AND 300-K. W., 120-VOLT CROCKER-WHEELER ENGINE-TYPE GENERATORS

power required for or developed by it, is found by multiplying its pull by its speed and by the circumference on which the pull is measured, and dividing by 33,000. That is,

$$\text{Horse-power} = \frac{P \times S \times 6.28 \times R}{33,000},$$

in which P is the pull in pounds, S the speed in revolutions per minute, and R the radius in feet at which P is measured.

Efficiency. This is determined in the case of a generator by dividing the electrical power generated by it by the mechanical power required to drive it; that is,

$$\text{Efficiency of generator} = \frac{\text{Electrical power}}{\text{Mechanical power}}.$$

The efficiency of a motor is the mechanical power developed by it, divided by the electrical power supplied to it; that is,

$$\text{Efficiency of motor} = \frac{\text{Mechanical power}}{\text{Electrical power}}.$$

These are the **actual or commercial efficiencies** of these machines, and should be at least 90 per cent at rated load in machines of 10 H. P. and over.

The so-called "electrical efficiency" is misleading and of little practical importance, and should not be considered in commercial work. The mechanical and electrical power in the above equations are determined as already explained.

It is usually more convenient to test the efficiency of a generator by testing it as a motor with a Prony brake. But the efficiency of a generator may be determined very easily by driving it with a calibrated electric motor, that is, one in which the power developed for any given number of volts and amperes consumed is known. Then it is only necessary to measure the watts supplied by the generator when the motor is running at a certain power, and the efficiency of the generator is *the watts ÷ the known power*.

Another method is to employ two identical machines, one used as a motor driving the other as a generator. The shafts of the two machines should be directly connected by some form of coupling; a belt may be used, but its friction would cause a

small loss. The watts produced by the generator, divided by the watts consumed by the motor, is the combined efficiency of the two machines; and the efficiency of each is the square root of that fraction. For example, if the combined efficiency is .81, then that of each machine is .90, since $.90 \times .90 = .81$. This assumes that the two efficiencies are equal, which is sufficiently correct if the machines are exactly alike. The current from the generator may be used to help feed the motor, and then only the difference in current need be supplied. This latter current represents the inefficiency or losses from friction, etc., in both machines.

To test in this way, connect both machines in parallel with the source of current; couple or belt them together; and then weaken the field, or shift the brushes of the machine which is to be used as a motor, so that it will speed up and drive the other as a dynamo, or cause it to drive the other by putting a large pulley on it. In this way the motor will consume current from the circuit while the generator yields current to the circuit. Both currents are measured and the efficiencies calculated.

The efficiency of a motor-generator or ordinary converter is very easily determined by simply measuring the input and output in watts (by wattmeters or by ammeters and voltmeters for direct currents), and dividing the latter by the former.

These electrical methods of testing are preferable to mechanical, for the reason that the volts and amperes can be easily and accurately measured, and their product gives the power in watts.* Mechanical measurements of power by dynamometer or other means are difficult, and usually not very accurate.

Separation of Losses. The total losses in a generator or motor, except that caused by the electrical resistance of the armature when carrying the full current, can be closely determined at once by noting the current required to run the machine free as a motor. In a machine of 90 per cent efficiency, this should not amount to more than about 8 per cent of the current required to give rated power. Consequently the easiest way to test a machine is to run it as a motor without load.

The various losses of power that occur in a generator or motor may be determined and separated from each other as follows:

* When alternating-current machinery is being tested use wattmeters

Take a generator, for example, and drive it with another machine used as a motor in the manner described for testing friction. The motor should previously be calibrated, that is, tested to determine the exact mechanical power it develops for each amount of electrical power in watts supplied to it, as described for testing efficiency. A simple, shunt-wound motor on a constant-potential circuit is best suited to the purpose. The generator is first driven at normal speed with no field magnetism and with the brushes lifted; then the actual power developed by the motor equals the power lost in the generator by the friction of bearings and belt. The brushes are then adjusted in contact with the commutator, with the usual pressure. The increase in the power of the motor is equal to the brush friction.

Finally, excite the field magnet to full strength, and the increase in the power exerted by the motor is equal to the combined losses due to the Foucault or eddy currents and hysteresis in the iron core of the armature, provided there is no considerable side pull on the armature. The power wasted in Foucault currents varies as the square of the speed, while the hysteretic loss is only directly proportional to speed; hence the two may be separated by testing the machine at different speeds.

For example, let us call x and y the losses due to hysteresis and Foucault currents, respectively, at full speed; A the power consumed by both at full speed; and B the power consumed at half speed. Then $A = x + y$, and $B = \frac{x}{2} + \frac{y}{4}$; hence, by eliminating x , we have $y = 2A - 4B$. That is the Foucault loss is twice the power consumed by both at full speed minus four times the power consumed by both at half speed. The hysteresis loss $= A - y$. If eddy currents are developed in the copper conductors of the armature, they will increase the apparent Foucault loss as determined by the above test, since they also vary as the square of the speed. The power wasted by eddy currents might be found by testing the armature without any conductors upon it. This could be done only before the armature is wound or by unwinding it, neither of which is practicable except in the place where it is made. Ordinarily, however, eddy currents in the conductors do not amount to much unless they are very

large, and even then the use of stranded conductors or conductors embedded in slots in the iron core largely overcomes the trouble.

Friction of the air might also increase the apparent Foucault loss; but it usually causes only a very small loss, and is almost impossible to separate except by running the machine in a vacuum, which is, of course, impracticable. The other losses are quite easily measured and separated, as follows :

The number of watts used in the field can be measured by a voltmeter and ammeter, or it can be calculated by the formula :

$$\text{Watts} = \frac{E^2}{R} = I^2R = EI, \text{ in which } E \text{ is the voltage, } R \text{ the}$$

resistance, and I the current. It is sufficient if any of these two quantities are known. The loss in the armature conductors, due to ohmic resistance is found by multiplying the square of the current in the armature at full load by the armature resistance; in fact, this is usually called the " I^2R loss." This should not be more than 1 to 3 per cent in a constant-potential generator or motor, whether it be alternating or direct-current. The sum of all the losses make up the difference between the total power consumed by the machine and the useful power that it develops.

The ordinary values of the various losses in a good generator or motor of 25 H. P. are approximately as follows :

Useful power developed.....	about 92 per cent.
Used in magnetizing field.....	about 1 to 2 "
Loss in armature resistance (I^2R)....	" 1 to 2 "
Friction of bearings	about 2 "
Friction of brushes.....	" $\frac{1}{2}$ "
Friction of air.....	" $\frac{1}{2}$ "
Hysteresis in armature core	" $1\frac{1}{2}$ "
Foucault currents in armature core....	" $1\frac{1}{2}$ "

Measurement of Power in A. C. Circuits. In circuits carrying alternating currents and having some inductive load either in the form of motors or arc lamps or a partly loaded transformer, etc., the ordinary method of determining the power, by voltmeter and ammeter measurements, is not applicable, as the current is seldom in phase with the E. M. F., and therefore the product *volts* $\times$ *amperes* is not the true power.

There are several means for determining the true power of an A. C. circuit, the simplest being an indicating wattmeter. A

wattmeter is an electro-dynamometer provided with two coils, a fixed one of coarse wire, the other movable and of fine wire. This movable coil is connected in series with a large non-inductive resistance, so that the time-constant of the fine-wire circuit is

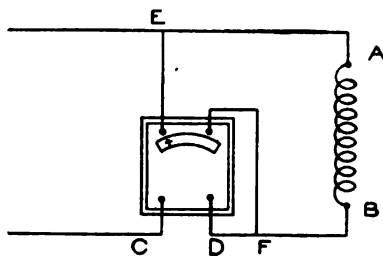


Fig. 52.

extremely small; and hence its impedance is practically equal to its resistance; the current in, and resulting field of, the fine-wire coil will under these conditions be practically in phase with the potential difference across its terminals. The field produced by the coarse-wire coil is directly proportional to the current flow-

ing through it at any instant. Hence, the couple acting on the fine-wire coil is proportional at a given instant to the product of these fields; so that the reading of the instrument, which depends on the mean value of the couple, will be proportional to the mean power, and, by providing the instrument with the proper scale, it can be made to read directly in watts.

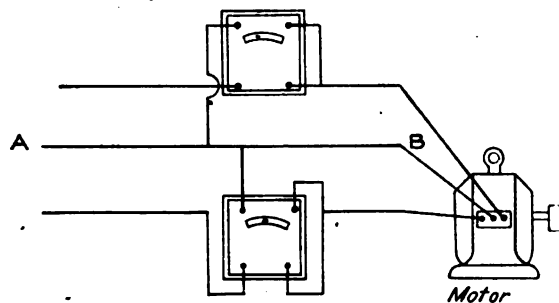


Fig. 53.

In Fig. 52, A B represents an inductive load—say, a single-phase motor—of which the power input is to be determined; C D the terminals of the thick-wire coil (current-coil) of the wattmeter; and E F the pressure-coil terminals. When connected as above indicated, the wattmeter indicates directly the power in watts supplied. In the case of a two-phase system, where the two circuits are independent, the power may be measured by placing a watt-

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meter in each phase, as shown in Fig. 52, and adding the two readings. If the motor be connected up as shown in Fig. 53, * where A B forms a common return, the wattmeters are placed as indicated, care being taken to place the current-coils in the out-

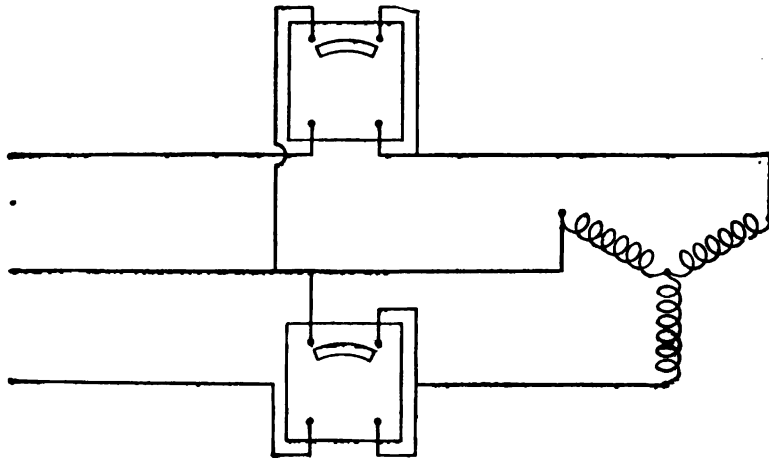


Fig. 54a.

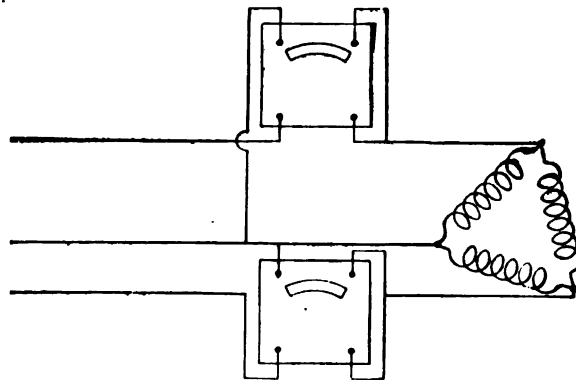


Fig. 54b.

side mains; and the power supplied is equal to the sum of the two wattmeter readings.

The power of a balanced or unbalanced three-phase system can be determined by the use of two wattmeters connected as

* This form of connection is possible only when the generator has two independent windings, one for each phase.

shown in Fig. 54, *a* and *b*. The current-carrying coils are placed in series with two of the wires, and the pressure-coil respectively connected between these two mains and the third wire. The

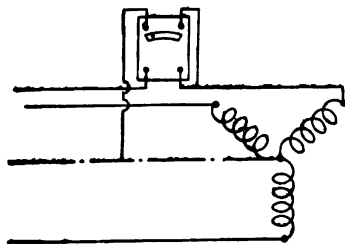


Fig. 55.

algebraic sum of these two wattmeter readings gives the true power supplied. When the power factor of the system is less than .5, one of the wattmeters will read negatively. It is sometimes difficult to determine whether the smaller readings are negative or not. If in doubt, give the wattmeter a separate load of incandescent lamps, and make the connections

such that both instruments deflect properly; then reconnect them to the load to be measured. If the terminals of one instrument have to be reversed, the readings of that wattmeter are negative.

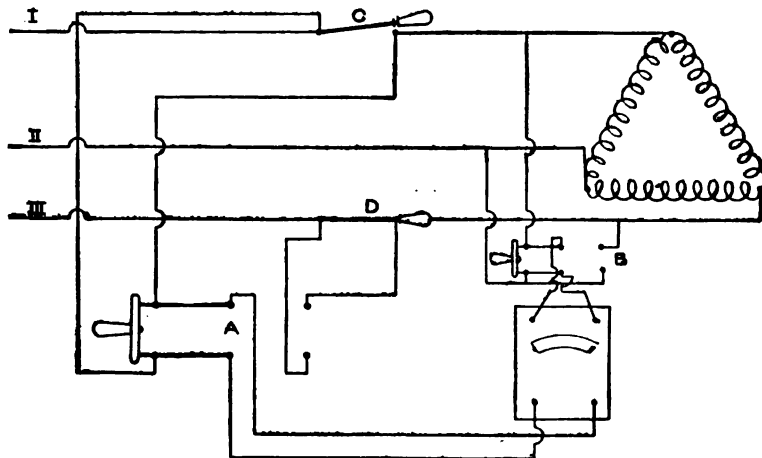


Fig. 56.

To measure the power of a balanced 4-wire 3 phase system, one wattmeter may be connected as shown in Fig. 55, and the wattmeter reading multiplied by 3. Usually, however, a 4-wire 3-phase system is unbalanced; and to determine the power supplied under this condition, three wattmeters should be employed, one for each phase, the power supplied being equal to the algebraic sum of all three readings.

It is obvious that in any of the above instances one wattmeter could be employed, provided the necessary switches are furnished. Assuming, for example, the 3-phase 3-wire case, one wattmeter would require switch connections as shown in Fig. 56. A is a double-pole switch, which, when thrown to the left, places the current-coil of the wattmeter in series with the conductor of No. I, and, when thrown to the right, places it in series with No. III. Similarly, switch B changes the pressure terminals from between I and II to III and II; while switches C and D are short-circuiting switches, one of which is closed previous to removing the current-coil from one phase to the other, and the other one opened after the coil is in position as indicated.

LOCALIZATION AND REMEDY OF TROUBLES.

The promptness and ease with which any accident or difficulty with electrical machinery can be dealt with, will always have much to do with the success of a plant. The following list of troubles, symptoms, and remedies for the various types and sizes of dynamos and motors in common use, has been prepared to facilitate the detection and elimination of such difficulties.

It is evident that the subject is somewhat complicated and difficult to handle in a general way, since so much depends upon the particular conditions in any given case, every one of which must be included in the table in such a way as to distinguish it from all others. Nevertheless, it is remarkable how much can be covered by a systematic statement of the matter, and nearly all cases of trouble most likely to occur are covered by the table, so that the detection and remedy of the defect will result from a proper application of the rules given.

It frequently happens that a trifling oversight, such as allowing a wire to slip out of a binding-post, will cause as much annoyance and delay in the use of electrical machinery as the most serious accident. Other troubles, equally simple but not so easily detected, are of frequent occurrence.

The rules are made, as far as possible, self-explanatory; but a statement of the general plan followed and its most important features will facilitate the understanding and use of the table.

USE OF THE TABLE OF TROUBLES.

In the use of this table, the principal object should be to separate clearly the various causes and effects from one another. A careful and thorough examination should first be made; and, as far as possible, one should be perfectly sure of the facts, rather than attempt to guess what they are and jump at conclusions. Of course, general precautions and preventive measures should be taken before any troubles occur, if possible, rather than to wait until a difficulty has arisen. For example, one should see that the machine is not overloaded or running at too high voltage, and should make sure that the oil-cups are not empty. Neglect and carelessness with any machine are usually and deservedly followed by accidents of some sort. It is usually wise to stop the machine when any trouble manifests itself, even though it does not seem to be very serious. It is often practically impossible to shut down; but even then, spare apparatus should be ready. The continued use of defective machinery is a common but very objectionable practice.

The general plan of the table is to divide all troubles that may occur to generators or motors, into ten classes, the headings of which are the ten most important and obvious bad effects produced in these machines, *viz.*:

- I. Sparking at Commutator.**
- II. Heating of Commutator and Brushes.**
- III. Heating of Armature.**
- IV. Heating of Field Magnets.**
- V. Heating of Bearings.**
- VI. Noisy Operation.**
- VII. Speed not right.**
- VIII. Motor stops or fails to start.**
- IX. Dynamo fails to generate.**
- X. Voltage not right.**

Any one of these general effects is evident, even to the casual observer, and still more so to any person making a careful examination; hence nine-tenths of the possible cases can be eliminated immediately.

The next step is to find out which particular one of the eight or ten causes in this class is responsible for the trouble. This requires more careful examination, but nevertheless can be done with comparative ease in most cases. One cause may produce

two effects, and, *vice versa*, one effect may be produced by two causes; but the table is arranged to cover this fact as far as possible. In a complicated or difficult case it is well to read through the entire table and note what causes can possibly apply. Generally there will not be more than two or three; and the particular one can be picked out by following the directions, which show how each case may be distinguished from any other.

I. SPARKING AT THE COMMUTATOR.

This is one of the most common of troubles, being often quite serious because it burns and cuts the commutator and brushes, at the same time producing heat that may spread to and injure the armature or bearings. Any machine having a commutator is liable to it, including practically all direct-current and some alternating-current machines. The latter usually have continuous collecting rings not likely to spark; but self-exciting or composite-wound alternators, rotary converters, and some alternating-current motors have supplementary direct-current commutators. A certain amount of sparking occurs normally in most constant-current dynamos for arc lighting, where it is not very objectionable, since the machines are designed to stand it and the current is small.

CAUSE 1. Armature carrying too much current, due to (*a*) overload (for example, too many lamps fed by dynamo, or too much mechanical work done by motor; a short circuit, leak, or ground on the line may also have the effect of overloading a dynamo); (*b*) excessive voltage on a constant-potential circuit, or excessive amperes on a constant-current circuit. In the case of a motor, any friction, such as armature striking pole pieces, or a shaft not turning freely, may have the same effect as overload.

SYMPTOM. Whole armature becomes overheated, and belt (if any) becomes very tight on tension side, sometimes squeaking because of slipping on pulley. Overload due to friction is detected by stopping the machine, and then turning it slowly by hand. (See V and VI, 2.)

REMEDY. (*a*) Reduce the load; or eliminate the short circuit, leak, or ground on the line; (*b*) decrease size of driving pulley, or (*c*) increase size of driven pulley; (*d*) decrease magnetic strength of field in the case of a dynamo, or increase it in the case

of a motor. If excess of current cannot satisfactorily be overcome in any of the above ways, it will be necessary to change the machine or its winding. Overload due to friction is eliminated as described under V and VI, 2.

If the starting or regulating rheostat of a motor has too little resistance, it will cause the motor to start too suddenly and to spark badly at first. The only remedy is more resistance in the box.

CAUSE 2, Brushes not set at the neutral point.

SYMPTOM. Sparking varied by shifting the brushes with rocker-arm.

REMEDY. Carefully shift brushes backwards or forwards until sparking is reduced to a minimum. This can be done by

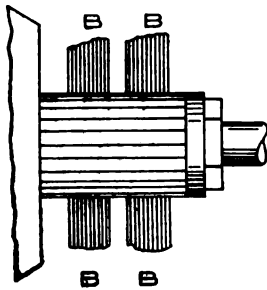


Fig. 57.

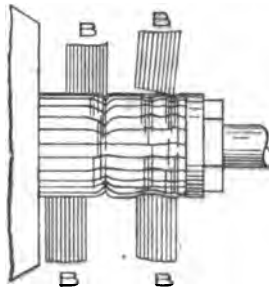


Fig. 58.



Fig. 59.

simply moving the rocker-arm. If only slightly out of position, heating alone may result, without disarrangement being bad enough to show sparking. If the brushes are not exactly opposite in a bipolar, 90° apart in a four-pole machine, and so on, they should be made so, the proper points of contact being determined by counting the commutator-bars or by careful measurement.

The usual position for brushes is opposite the spaces between the pole pieces, but in some machines they must be set in line with centers of pole pieces or at some other point. If the brushes are set exactly wrong, this will cause a dynamo to fail to generate, and a motor to fail to start, and will blow the fuse or open the circuit-breaker. (See IX, 6.)

CAUSE 3. Commutator rough, eccentric, or has one or more "high bars" projecting beyond the others, or one or more

flat bars, commonly called **flats**, or **projecting mica**, any one of which causes the brushes to vibrate or to be actually thrown out of contact with the commutator (Figs. 58 and 59). Hard mica between the bars, which does not wear as rapidly as the copper, will prevent good contact or throw brushes off.

SYMPTOM. Note whether there is a glaze or polish on the commutator, which shows smooth working; touch revolving commutator with tip of finger nail, and the least roughness is perceptible; or feel brushes to see if there is any jar. If the machine runs at high voltage (over 250), the commutator or brushes should be touched with a stick or quill to avoid danger of shock. In the case of an eccentric commutator, careful examination shows a rise and fall of the brush when the commutator turns slowly, or a chattering of brush when it is running fast. Sometimes, by sighting in line with brush contact, one can see daylight between commutator and brush, owing to brush jumping up and down.

REMEDY. Smooth the commutator with a fine file or fine sandpaper, which should be applied on a block of wood that exactly fits the commutator (being careful to remove any sand remaining afterward; and *never use emery*). If commutator is very rough or eccentric, the armature should be taken out and put in a lathe, and the commutator turned off. Large machines often have a slide-rest attachment (Fig. 60), so that the commutator can be turned off without removing the armature. This is clasped on the pillow-block after removing the rocker-arm.

For turning off a commutator, a diamond-pointed tool should be used, this being better than either a round or square end. It should have a very sharp and smooth edge; and only a fine cut should be taken off each time in order to avoid catching in or tearing the copper, which is very tough. The surface is then finished

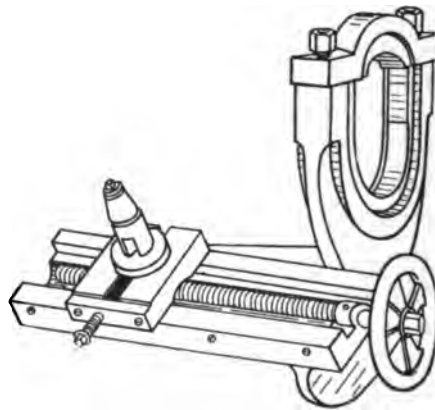


Fig. 60.

by applying a "dead smooth" file while the commutator revolves rapidly in the lathe. Any particles of copper should then be carefully removed from between the bars.

To have the commutator wear smooth and work well, it is desirable to have the armature shaft move freely back and forth about an eighth of an inch in the bearings while it is running. A commutator should have a glaze of a brown or bronze color. A very bright or scraped appearance does not indicate the best condition. Sometimes a very little vaseline or a drop of oil may be applied to a commutator that is rough. Too much oil is very bad, and causes the following trouble:

CAUSE 4. Brushes make poor contact with commutator.

SYMPTOM. Close examination shows that brushes touch only at one corner, or only in front or behind, or there is dirt on surface of contact. Sometimes, owing to the presence of too much oil or from other cause, the brushes and commutator become very dirty, and covered with smut. They should then be carefully cleaned by wiping with oily rag or benzine, or by other means.

Occasionally a "glass-hard" carbon brush is met with. It is incapable of wearing to a good seat or contact, and will touch at only one or two points. Some carbon brushes are of abnormally high resistance, so that they do not make good contact. In such cases new brushes should be substituted.

REMEDY. Carefully fit, adjust, or clean brushes until they rest evenly on commutator, with considerable surface of contact and with sure but not too heavy pressure. Copper brushes require a regular brush jig (Fig. 61). Carbon brushes can be fitted perfectly by drawing a strip of sandpaper back and forth between them and the commutator while they are pressing down. A band of sandpaper may be pasted or tied around the commutator, and the armature then slowly revolved by hand or by power while the brushes are pressed upon it.

It sometimes happens that the brushes make poor contact because the brush-holders do not work freely.

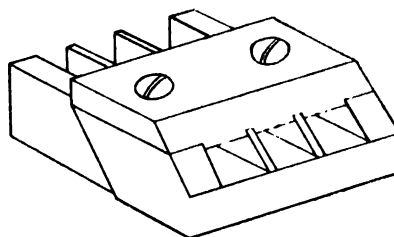


Fig. 61.

CAUSE 5. Short-circuited or reversed coil or coils in armature.

SYMPTOM. A motor will draw excessive current, even when running free without load. A dynamo will require considerable power, even without any load. For reversed coil, see III, 5.

The short-circuited coil is heated much more than the others, and is liable to be burnt out entirely; therefore the machine should be stopped immediately. If necessary to run machine in order to locate the trouble, one or two minutes is long enough; but this may be repeated until the short-circuited coil is found by feeling the armature all over.

An iron screw-driver or other tool held between the field magnets near the revolving armature, vibrates very perceptibly as the short-circuited coil passes. Almost any armature, particularly one with teeth, will cause a slight but rapid vibration of a piece of iron held near it; but a short circuit produces a much stronger effect only *once* per revolution. Care should be taken not to let the piece of iron be drawn in and jam the armature.

The current pulsates and torque is unequal at different parts of a revolution, these being particularly noticeable when several coils are short-circuited or reversed and the armature is slowly turned. If a large portion of the armature is short-circuited, the heating is distributed and is harder to locate. In this case a motor runs very slowly, giving little power but having full field magnetism. A short-circuited coil can also be detected by the drop-of-potential method. For dynamos, see IX, 3.

REMEDY. A short circuit is often caused by a piece of solder or other metal getting between the commutator-bars or their connections with the armature; and sometimes the insulation between or at the ends of these bars is bridged over by a particle of metal. In any such case the trouble is easily found and corrected. If, however, the short circuit is in the coil itself, the only effective remedy is to rewind the coil.

One or more "grounds" in the armature may produce effects similar to those arising from a short circuit. (See Cause 7.)

CAUSE 6. Broken circuit in armature.

SYMPTOM. Commutator flashes violently while running, and commutator-bar nearest the break is badly cut and burnt; but in

this case no particular armature coil will be heated as in the last case; and the flashing will be very much worse, even when turning slowly. This trouble, which might be confounded with a bad case of "high bar" in commutator (Cause 3), is distinguished therefrom by slowly turning the armature, when violent flashing will continue if circuit is broken; but not with "high bar" unless it is very bad, in which case it is easily felt or seen. A very bad contact has almost the same effect as a break in the circuit.

REMEDY. A break or bad contact can be located by the "drop" method (page 63) or by a continuity test (page 68). The trouble is often found where the armature wires connect with the commutator, and not in the coil itself, and the break may be repaired or the loose wire properly fastened. If the trouble is due to a broken commutator connection, and cannot be fixed, the disconnected bar may be temporarily connected

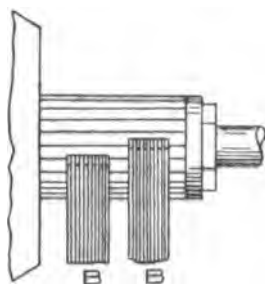


Fig. 62.

to the next by solder, or the brushes may be "staggered," that is, one put a little forward and the other back so as to bridge over the break (Fig. 62). It may be impracticable to "stagger" radial and some other arrangements of brushes, but usually a brush is thick enough to make contact with more than one commutator bar. If the break is in the coil itself, rewinding is generally the only cure. But this may be

remedied temporarily by connecting together by wire or solder the two commutator-bars or coil-terminals between which the break exists. It is only in an emergency that armature coils should be cut out or commutator bars connected together, or other makeshifts resorted to; but it sometimes avoids a very undesirable stoppage. A very rough but quick and simple way to connect two commutator bars, is to hammer or otherwise force the coppers together across the mica insulation at the end of the commutator. This should be avoided if possible; but if it has to be done in an emergency, the crushed material can afterwards be picked out and the injury smoothed over. In carrying out any of these methods, great care should be taken not to short-circuit any other armature coil, which would cause sparking (Cause 5).

CAUSE 7. Ground in Armature.

SYMPTOM. Two "grounds" (accidental connections between the conductors on the armature and its iron core or the shaft or spider) would have practically the same effect as a short circuit (Cause 5), and would be treated in the same way. A single ground would have little or no effect, provided the circuit is not intentionally or accidentally grounded at some other point. On an electric-railway ("trolley") or other circuit employing the earth as a return conductor, one or more grounds in the armature would allow the current to pass directly through them, and would cause the motor to spark and have a variable torque at different parts of a revolution.

REMEDY. A ground can be detected by testing with a magneto bell (page 67). It can also be located by the drop-of-potential method (page 63). Another way to locate it is to wrap a wire around the commutator so as to make connection with all of the bars, and then connect a source of current to this wire and to the armature core (by pressing a wire upon the latter). The current will then flow from the armature conductors through the ground connection to the core, and the magnetic effect of the armature winding will be localized at the point where the ground is. This point is then found by the indications of a compass needle when slowly moved around the surface of the armature. The current may be obtained from a storage battery or from the circuit, but should be regulated by lamps or other resistance so as not to exceed the normal armature current. Sometimes the ground may be in a place where it can be corrected without much trouble, but usually the particular coil and often others must be rewound. A ground will be produced if the insulation is punctured by a spark of static electricity, which may be generated by the friction of the belt. If the frame of the machine is connected to the ground, the static charge will pass off to the ground; but such grounding is often inadvisable, and in such cases the frame may be connected to the ground through a Geissler tube, a wet thread, a heavy pencil-mark on a piece of unglazed porcelain, or other very high resistance which will carry off a static charge of very high potential and almost infinitesimal quantity, but will not permit the passage of any considerable current that might cause trouble.



1,200-K. W., 250-VOLT, SLOW-SPEED, CROCKER-WHEELER D. C. LIGHTING AND POWER GENERATORS. DIRECT-CONNECTED

CAUSE 8. Weak Field Magnetism.

SYMPTOM. Pole pieces not strongly magnetic when tested with a piece of iron. Point of least sparking is shifted considerably from normal position, owing to relatively strong distorting effect of armature magnetism. Speed of a shunt motor is usually high unless magnetism is very weak or *nil*, in which case a motor may run slow, stop, or even run backwards.* A generator fails to generate the full E.M.F. or current.

The particular cause of trouble may be found as follows: A broken circuit in the field of a motor is found by purposely opening the field circuit at some point, taking care first to disconnect armature (by putting wood under the brushes, for example), and to use only one hand, to avoid shock. If there is no spark when circuit is thus opened, there must be a broken circuit somewhere. A short circuit in the field coils is found by measuring their resistance roughly to see if it is very much less than it should be. Usually a short circuit is confined to one magnet, and will therefore weaken that one more than the others; and a piece of iron held half-way between the pole pieces will be attracted to one more than to the other. The short circuit may be found by the drop-of-potential method, by testing from the joint between the field coils to each outside terminal. "Grounding" is practically identical with short-circuiting, but one ground will not produce this effect until another occurs. A double ground, through which the current finds a complete path, is equivalent to a short circuit. In the ordinary "trolley" electric-railway system, a ground return is used, and the neutral conductor of three-wire systems is often grounded. In such cases one ground may be sufficient to cut out one or more field coils.

If one field coil is reversed and opposed to the others, it will weaken the field magnetism and cause bad sparking. This may be detected by examining the field coils to see if they are all connected in the right way, or by testing with a compass needle. (See IX, 4.) The series-coil of a compound-wound dynamo or motor is often connected wrongly, and will have the wrong effect, that is, will reduce the voltage of the former or raise the speed of the latter with increase of load.

* **NOTE.** If the motor is not loaded, it will race.

REMEDY. A broken or short circuit or a ground is easily repaired if external or accessible. If it is internal, the only remedy is to replace or rewind the faulty coil. A shunt motor will spark badly in starting if the armature is connected before the field. This can be remedied by adjusting the contacts and switch-arm. If the voltage is too low on the circuit, it may cause sparking in a shunt dynamo or motor; and if the voltage cannot be raised, the resistance of the field circuit should be reduced by unwinding a few layers of wire or by substituting other coils (See VII, VIII, IX, and X.)

CAUSE 9. Vibration of Machine.

SYMPTOM. Considerable vibration is felt when the hand is placed upon the machine, and sparking decreases if the vibration is reduced.

REMEDY. The vibration is usually due to an imperfectly balanced armature or pulley (see VI, 1), to a bad belt (see VI, 6), or to unsteady foundations; and the remedies described for these troubles should be applied.

Any considerable vibration is likely to produce sparking, of which it is a common cause. This sparking can be reduced by increasing the pressure of the brushes on the commutator, but the vibration itself should be overcome.

CAUSE 10. Chatter of Brushes.

The commutator sometimes becomes sticky when carbon brushes are used, causing friction, which throws the brushes into rapid vibration as the commutator revolves, similar to the action of a violin bow.

SYMPTOM. Slight tingling or jarring is felt in brushes.

REMEDY. Clean commutator, and oil slightly.

CAUSE 11. Flying break in armature conductor.

SYMPTOM. No break found by test with armature standing still, but break shown by flashing at brushes when running, being usually due to centrifugal force.

REMEDY. Tighten connections to commutator, or repair broken wire, etc.

EXCESSIVE HEATING IN GENERATOR OR MOTOR.

General Instructions. The degree of heat that is injurious or objectionable in a generator or motor is easily determined by

feeling the various parts. If the heat is bearable to the hand, it is entirely harmless; but if unbearable, the safe limit of temperature has been approached or passed, and the heat should be reduced in some of the ways that are indicated below. In testing with the hand, allowance should be made for the fact that bare metal feels much hotter than cotton at the same temperature. The back of the hand is more sensitive than the palm for this test. If the heat has become so great as to produce an odor or smoke, the safe limit has been far exceeded, and the current should be shut off immediately and the machine stopped, as this indicates a serious trouble, such as a short-circuited coil or tight bearing. The machine should not again be started until the cause of the trouble has been found and positively overcome. Of course, neither water nor ice should ever be used to cool electrical machinery, except possibly the bearings of large machines at points where they can be applied without danger of wetting the other parts.

Feeling for heat will serve as a rough test to detect excessive temperatures or in emergencies; but, of course, the sensitiveness of the hand varies, and it makes a great difference whether the surface is a good or bad conductor of heat. The proper and reliable methods for determining rise in temperature are given on page 59, Part I.

It is very important, in all cases of heating, to locate the source of heat in the exact part in which it is produced. It is a common mistake to suppose that any part of a machine that is found to be hot is the seat of the trouble. A hot bearing may cause the armature or commutator to heat, or *vice versa*. In every case all parts of the machine should be tried to find which is the hottest, since heat generated in one part is rapidly diffused throughout the entire machine. It is better to make observations for heating by starting with the whole machine cool, which is done by letting it stand for several hours.

II. HEATING OF COMMUTATOR AND BRUSHES.

CAUSE 1. Heat spread from another part of machine.

SYMPTOM. Start with the machine cool, and run for a short time, so that heat will not have time to spread. The real seat of trouble is the part that heats first.

REMEDY. (See Heating of Armature, Fields, and Bearings.)

CAUSE 2. **Sparking.** Any of the causes of sparking will cause heating, which may be slight or serious.

SYMPTOM and REMEDY. See "Sparking."

CAUSE 3. **Tendency to spark, or slight sparking hardly visible.**

Sometimes before sparking appears, serious heating is produced by the causes of sparking, such as the short-circuiting of the coils as their commutator-bars pass under the brushes.

SYMPTOM. Reduced by applying the principal remedies for sparking, such as slightly shifting rocker-arm. Fine sparks may be found by sighting in exact line with the surface of contact between the commutator and brushes.

REMEDY. (See "Sparking.") Apply the remedies with extra care. This incipient sparking may be due to excessive inductance in the armature coils, which can be corrected only by reconstruction; or it may be due to insufficient field strength, and this can be cured by increasing the ampero-turns of field winding.

CAUSE 4. **Overheated commutator will decompose carbon brush.**

The effect is to cover commutator with a black film which offers resistance and aggravates the heat.

SYMPTOM. Commutator covered with dark coating; commutator, brushes and holders show marks of abnormal heat.

REMEDY. Commutator and brushes should be carefully cleaned; and the latter adjusted to make good contact at the proper points.

CAUSE 5. **Bad connections in brush-holder, cable, etc.**

SYMPTOM. Holder, cable, etc., feel hottest; unusual resistance found in these parts by "drop method."

REMEDY. Improve the connections.

CAUSE 6. **Arcing or short circuit in commutator.**

This may occur across mica or insulation between bars or nuts.

SYMPTOM. Burnt spot between parts; spark appears in the insulation when current is put on.

REMEDY. Pick out the charred particles; take commutator apart and repair; or put on new commutator.

CAUSE 7. **Carbon brushes heated by the current.**

Carbon brushes require less attention than copper, because they do not cut the commutator, and their resistance usually reduces sparking, but it may also cause them to heat.

SYMPTOM. Brushes hotter than other parts.

REMEDY. Use carbon of higher conductivity. Let the brush-holder grip brush closer to commutator, so as to reduce the length of brush through which the current must pass. Reinforce the brush with copper gauze or sheet copper. Use larger brushes or a greater number.

III. HEATING OF ARMATURE.

CAUSE 1. Excessive current in armature coils.

SYMPTOM and **REMEDY** the same as in case of "Sparking,"

Cause 1.

CAUSE 2. Short-circuited armature coils.

SYMPTOM and **REMEDY** the same as in case of "Sparking,"

Cause 5. See also Cause 7.

CAUSE 3. Moisture in armature coils.

SYMPTOM. Armature requires considerable power to run free. Armature steams when hot, or feels moist. This is really a special case of Cause 2, as moisture has the effect of short-circuiting the coils through the insulation. Measure insulation resistance of armature; this should test at least one megohm if armature is in good condition, but would be much lowered by moisture. (See "Insulation Tests.")

REMEDY. The armature should be baked for 5 to 10 hours in an oven or other place sufficiently warm to drive out the moisture, but not hot enough to run any risk of burning or even slightly charring the insulation. A neat way to do this is to pass through the armature a current regulated to be about three quarters of the rated armature current, the armature being held still or turned over occasionally.

CAUSE 4. Foucault currents in armature core.

SYMPTOM. Iron of armature core hotter than coils after a short run, and considerable power required to run armature when

NOTE. Any excess of current taken by an armature when running *free*, whatever the cause, must be converted into heat by some defect in the motor; hence the "free current" is the simplest and most complete test of the efficiency and perfect condition of the machine.

field is magnetized and there is no load on armature. This can be distinguished from Cause 2 by absence of sparking and absence of excessive heat in a particular coil or coils after a short run. (See "Stray Power Tests.")

REMEDY. Armature core should be laminated more perfectly, which is a matter of first construction.

CAUSE 5. One or more reversed coils on one side of armature. This will cause a local current to circulate around armature.

SYMPTOM. Excessive current when running free, but no particular coil heated more than others. If a moderate current is applied to each coil in succession by touching wires carrying current to each two adjacent commutator-bars, a compass needle held over the coils will behave differently when the reversed coil is reached. In a motor the half of armature containing the reversed coils is heated more than the other.

REMEDY. Reconnect the coil to agree with the others.

CAUSE 6. Heat conveyed from other parts.

SYMPTOM. Other parts hotter than armature. Start with machine cool, and see if other parts heat first.

REMEDY. See Heating of Bearings, Field and Commutator.

CAUSE 7. Flying cross in armature conductor.

SYMPTOM and REMEDY similar to the case of sparking (Cause 11), except that reference here is to the insulation of the conductors.

IV. HEATING OF FIELD MAGNETS.

CAUSE 1. Excessive current in field circuit.

SYMPTOM. Field coils too hot to keep the hand on. Their temperature more than 50°C above that of room by resistance test or by thermometer.

REMEDY. In the case of a shunt-wound machine, decrease the voltage at terminals of field coils; or increase the resistance in field circuit by winding on more wire or putting resistance in series. In the case of a series-wound machine, shunt a portion of, or otherwise decrease, the current passing through field; or take a layer or more of wire off the field coils; or rewind with coarser wire. This trouble might be due to a short circuit in field coils in the case of a shunt-wound dynamo or motor, and would be indicated by the

pole piece with the short-circuited coil being weaker than the others. This coil is cooler than the others; in fact, if completely short-circuited, it is not heated at all. This condition can be remedied only by rewinding the short-circuited coil. Measure resistance of the field coils to see if they are nearly equal. (See "drop method.") If the difference is considerable (say, more than 5 or 10 per cent), it is almost a sure sign that one coil is short-circuited or double-grounded.

CAUSE 2. Foucault currents in pole pieces or field cores.

SYMPTOM. The pole pieces hotter than the coils after a short run. When making the comparison, it is necessary to keep the hand on the coils some time before the full effect is reached, because the coils are insulated and the pole pieces are bare metal, and even then the coils will not feel so hot, although their actual temperature may be higher if measured by a thermometer.

REMEDY. This trouble is due to faulty design of toothed-armature machines, which can be corrected only by rebuilding, or is caused by fluctuations in the current. The latter can be detected, if the variations are not too rapid, by putting an ammeter in circuit; or rapid variations may be felt by holding a piece of iron near the pole pieces, and noting whether it vibrates. In the case of an alternating current it is necessary to use laminated fields to avoid great heating.

CAUSE 3. Moisture in field coils.

SYMPTOM. The field circuit tests lower in resistance than normal in that type of machine; and in the case of shunt-wound machines, the field takes more than the ordinary current. Field coils steam when hot, or feel moist to hand. The insulation resistance also tests low.

REMEDY. The same as for moisture in armature (III, 3).

V. HEATING OF BEARINGS.

The cause should be found and removed promptly, but heating of the bearings can be reduced temporarily by applying cold water or ice to them. This is allowable only when absolutely necessary to keep running; and great care should be taken not to allow any water to get upon the commutator, armature, or field-coils, as it might short-circuit or ground them. If the bearing is

very hot, the shaft should be kept revolving slowly, as it might "freeze," or stick fast, if stopped entirely.

CAUSE 1. Lack of oil.

SYMPTOM. Oil-cup reservoir empty. Oil passages clogged. Self-oiling rings stick fast. Shaft and bearing look dry. The shaft does not turn freely.

REMEDY. Supply oil, and make sure that oil passages as well as feeding or self-oiling devices work freely, and that the oil cannot leak out. This last fault sometimes causes oil to fail sooner than attendant expects. A good quality



Fig. 63.

of oil should always be used, as poor oil might be as bad as no oil.

CAUSE 2. Grit or other foreign matter in bearings.

SYMPTOM. Best detected by removing shaft or bearing and examining both. Any grit can of course be felt easily, and will also cut the shaft.

REMEDY. Remove shaft or bearing, clean both very carefully, and see that no grit can get in. Place machine in dustless place or box it in. The oil should be perfectly clean; if not, it should be filtered. If it is not possible to stop the machine or to remove the shaft, the dirt may be washed out with kerosene or water; but these should not be allowed to get on the commutator, armature, or field coils.

CAUSE 3. Shaft rough or cut. (Fig. 63.)

SYMPTOM. Shaft will show grooves or roughness, and will probably revolve stiffly.

REMEDY. Turn shaft in lathe; or smooth with fine file; and see that bearing is smooth and fits shaft.

CAUSE 4. Shaft and bearing fit too tight.

SYMPTOM. Shaft hard to revolve by hand.

REMEDY. Turn or file down shaft in lathe, or scrape or ream out bearings.

CAUSE 5. Shaft "sprung" or bent.

SYMPTOM. Shaft hard to revolve, and usually sticks much more in one part of revolution than in another.

REMEDY. It is very difficult to straighten a bent shaft. It might be bent back or turned true, but probably a new shaft will be necessary.

CAUSE 6. Bearings out of line.

SYMPTOM. Shaft hard to revolve, but is much relieved by slightly loosening the screws that hold bearings in place, when machine is not running and when belt, if any, is taken off.

REMEDY. Loosen the bearings by partly unscrewing bolts or screws holding them in place, and find their easy and true position, which may require one of them to be moved either sideways or up or down; then file the screw-holes of that bearing, or raise or lower it, as may be necessary, to make it occupy the right position when the screws are tightened. The armature, however, must be kept in the center of the space between the pole pieces, so that the clearance is uniform all around. (See Cause 9.)

CAUSE 7. Thrust or pressure of pulley, collar, or shoulder on shaft against one or both of the bearings.

SYMPTOM. Move shaft back and forth with a stick applied to the end while revolving, and note if the collar or shoulder tends to be pushed or drawn against either bearing. It is usually desirable that a shaft should move freely back and forth about an eighth of an inch, to make commutator and bearings wear smoothly.

REMEDY. Line up the belt; shift collar or pulley; turn off shoulder on shaft, or file off bearing, until the shoulder does not touch when running, or until pressure is relieved.

CAUSE 8. Too great a load or strain on the belt.

SYMPTOM. Great tension on belt. In this case the pulley bearing will probably be very much hotter than the other, and also worn elliptical, as indicated in Fig. 64, in which case the shaft can be shaken in the bearing in the direction of the belt pull, when the belt is off, provided the machine has been running long enough to wear the bearings.

REMEDY. Reduce load or belt tension, or use larger pulleys and lighter belt, so as to relieve side strain on shaft. (See "Belt-ing.")

CAUSE 9. Armature too near one pole piece, producing much greater magnetic attraction on nearer side.

SYMPTOM. Examine the clearance of armature to see if it is uniform on all sides. Charge and discharge the field magnet, the armature being disconnected (by putting wood under the brushes);

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and note whether armature seems to be drawn to one side and turns very much less easily when field is magnetized.

REMEDY. This fault is due either to a defect in the original construction, or to wear in the bearings, either of which is difficult to correct; but in cases of necessity the armature can be centered exactly in the field by moving the bearings, which may be done by carefully filing the holes through which the screws pass that hold the bearings in place; or the pole piece may be filed away where it is too near the armature.

Trouble from this cause is greater in multipolar than in bipolar machines, and always tends to become aggravated, because the more the side pull the more the bearings wear in that direction. If, on the other hand, the armature is in the center of the space formed by the pole pieces, the magnetic pull is practically balanced in all directions.

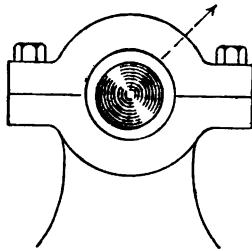


Fig. 64.

It is risky to file bolt-holes or make any such change in a machine; and this should never be attempted before consulting an experienced machinist. Very often the trouble is due to the parts being out of place merely because they have not been put together right

or because there is dirt between them. If the bearing is worn, it may be rebabbitted or renewed.

CAUSE 10. Bearing heated by hot pulley, commutator, or armature.

SYMPTOM. Pulley, armature, or commutator hotter than bearing. The slipping of the belt on the pulley, sparking at the commutator, or heating of the armature may heat one or both bearings of the machine, in which case an examination will show that these parts are hotter than the bearing, and the real source of the trouble.

REMEDY. A slipping belt, sparking commutator, or hot armature can be cured as described under these headings, and then the bearing will probably cease to heat.

VI. NOISY OPERATION.

CAUSE 1. Vibration due to armature or pulley being out of balance.

SYMPTOM. Strong vibration felt when the hand is placed upon the machine while it is running. Vibration changes greatly if speed is changed, and sometimes almost disappears at certain speeds.

REMEDY. Armature or pulley must be perfectly balanced by securely attaching lead or other weight on the light side, or by drilling or filing away some of the metal on the heavy side. The easiest method of finding in which direction the armature is out of balance is to take it out, and to rest the shaft on two parallel and horizontal A-shaped metallic tracks sufficiently far apart to allow the armature to go between them (Fig. 65). If the armature is then slowly rolled back and forth, the heavy side will tend to turn downward. The armature and pulley should always be balanced separately. An excess of weight on one side of the pulley and an equal excess of weight on the opposite side of the armature will not produce a balance while running, though it does when standing still; on the contrary, it will give the shaft a strong tendency to "wobble." A perfect balance is obtained only when the weights are directly opposite, *i.e.*, in the same line perpendicular to the shaft.

CAUSE 2. Armature strikes or rubs against pole pieces.

SYMPTOM. Easily detected by placing the ear near the pole pieces; or by examining armature to see if its surface is abraded at any point; or by examining each part of the space between armature and field as armature is slowly revolved, to see if any portion of it touches or is so close as to be likely to touch when the machine is running. In small machines, the armature may be turned by hand, noting whether it sticks at any point.

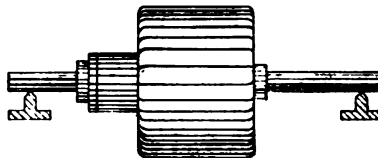


Fig. 65.

REMEDY. Bind down any wire or other part of the armature that may project abnormally; or file out the pole pieces where the armature strikes; or center the armature so that there is a uniform clearance between it and the pole pieces at all points.

CAUSE 3. Shaft collar or shoulder, hub or edge of pulley, or belt, strikes or scrapes against bearings.

SYMPTOM. Rattling noise, which stops when the shaft or pulley is pushed lengthwise away from one or the other of the bearings. (See "Heating of Bearings," Cause 7.)

REMEDY. Shift the collar or pulley, turn off the shoulder on the shaft, file or turn off the bearing, move the pulley on the shaft, or straighten the belt, until there is no more striking, and the noise ceases.

CAUSE 4. Rattling due to looseness of screws or other parts.

SYMPTOM. Close examination of the bearings, shaft, pulley, screws, nuts, binding-posts, etc., or touching the machine while running, or shaking its parts while standing still, shows that some parts are loose.

REMEDY. Tighten up the loose parts, and be careful to keep them all properly set up. It is easy to guard against the occurrence of this trouble, which is very common, by simply examining the various screws and other parts each day before the machine is started. Electrical machinery being usually high-speed, the parts are particularly liable to shake loose. A worn or poorly fitted bearing might allow the shaft to rattle and make a noise, in which case the bearing should be refitted or renewed.

CAUSE 5. Singing or hissing of brushes. This is usually occasioned by rough or sticky commutator (see "Sparkling," Causes 3 and 10), or by brushes not being smooth, or by the layers of a copper brush not being held together and in place. With carbon brushes, hissing will be caused by the use of carbon that is gritty or too hard. Vertical carbon brushes, or brushes inclined against the direction of rotation, are liable to squeak or sing. Occasionally, a new machine will make noise that is reduced after the machine has been run for some time.

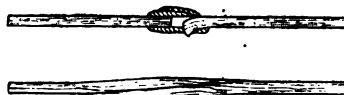


Fig. 66.

SYMPTOM. Sound of high pitch, and easily located by placing the ear near the commutator while it is running, and by lifting off the brushes one at a time, provided there are two or more in each set, so that the circuit is not opened. If there is no current there is no objection to raising the brushes.

REMEDY. Apply a *very little* oil or vaseline to the commu-

tator with the finger or a rag. Adjust the brushes or smooth the commutator by turning or filing, or by using fine sandpaper, being careful to clean thoroughly afterwards. Carbon brushes are liable to squeak in starting up or at low speed. This decreases at full speed, and can generally be stopped by moistening the brushes with oil, care being taken not to have any drops or excess of oil. Shortening or lengthening the brushes sometimes stops the noise. Running the machine without load for some time usually reduces this trouble.

CAUSE 6. Flapping or pounding of belt joint or lacing against pulley. (Fig. 66.)

SYMPTOM. Sound repeated once for each complete revolution of the belt, which is much less frequent than any other generator or motor sound, and can easily be detected or counted.

REMEDY. Endless belt or smoother joint. (See "Belting.")

CAUSE 7. Slipping of belt on pulley due to overload.

SYMPTOM. Intermittent squeaking noise.

REMEDY. Tighten the belt or reduce the load. A wider belt or larger pulley may be required. Powdered rosin may be put on the belt to increase its adhesion; but it is a makeshift, injurious to the belt, to be adopted only if necessary. (See "Belting.")

CAUSE 8. Humming of armature-core teeth as they pass pole-pieces.

SYMPTOM. Pure humming sound less metallic than Cause 5.

REMEDY. Slope or chamfer the ends of the pole pieces so that each armature tooth does not pass the edge of the pole piece all at once. Decrease the magnetization of the fields. Increase the air-gap or reduce the distance between the teeth. But these are nearly all matters of first construction and are made right by good manufacturers.

CAUSE 9. Humming due to alternating or pulsating current.

SYMPTOM This gives a sound similar to that in the preceding case. The two can be distinguished, if necessary, by determining whether the note given out corresponds to the number of alternations, or to the number of armature teeth passing per second.

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Usually the latter is considerably greater than the former.

REMEDY. This trouble is confined to alternating apparatus, and its effects can be reduced by proper design and by mounting the machine so as to deaden the sound as far as possible.

It often happens that a generator or motor seems to make a noise, which in reality is caused by the engine or other machine with which it is connected. Careful listening with the ear close to the different parts will show exactly where the noise originates. A very sensitive method of locating a noise or vibration is to hold a short stick by one end between the teeth, and press the other end squarely against the several parts, to ascertain which particular one gives the greatest vibration.

VII. SPEED TOO HIGH OR TOO LOW.

This is generally a serious matter in either generator or motor, and it is always desirable and often imperative to shut down immediately, and make a careful investigation.

SPEED TOO LOW.

CAUSE 1. Overload. (See "Sparking," Cause 1.)

SYMPTOM. Armature runs more slowly than usual. Bad sparking at commutator. Ammeter indicates excessive current. Armature heats. Belt very tight on tension side.

REMEDY. Reduce the load on machine, decrease the diameter of driving pulley, or increase the diameter of driven pulley. If necessary to relieve strain of overload, temporarily decrease the voltage on either a generator or a motor.

CAUSE 2. Short circuit or ground in armature.

SYMPTOM and REMEDY the same as in case of "Heating of Armature, Cause 2 and Cause 6.

CAUSE 3. Armature strikes pole pieces.

SYMPTOM and REMEDY the same as in case of "Noise," Cause 2.

CAUSE 4. Shaft does not revolve freely in the bearings.

SYMPTOM and REMEDY the same as for "Heating of Bearings," all cases.

SPEED TOO HIGH OR TOO LOW.

CAUSE 5. Field magnetism weak.

This has the effect, on a constant-voltage circuit, of making a motor run too fast if lightly loaded, or too slow if heavily loaded, or even run backwards if the field magnet is not excited at all, as,

for example, when the field circuit is broken. It makes a generator fail to "build up" or excite its field, or give the proper voltage in any case.

SYMPTOM and **REMEDY** the same as in case of "Sparking," Cause 8. (See the following Cause; also "Dynamo Fails to Generate.")

CAUSE 6. Too high or too low voltage on the circuit.

SYMPTOM. This would cause a motor to run too fast or too slow, respectively. It can be shown by measuring the voltage of the circuit.

REMEDY. The central station or generating plant should be notified that voltage is not right.

SPEED TOO HIGH.

CAUSE 7. Motor too lightly loaded.

SYMPTOM. A series-wound motor on a constant-potential circuit runs too fast, and may speed up to the bursting point if the load is very much reduced or removed entirely (by the breaking of the belt, for example).

REMEDY. Care should be exercised in using a series motor on a constant-potential circuit, except where the load is a fan, pump, or other machine that is *positively* connected or geared to the motor so that there is no danger of its being taken off. A shunt motor should be used if the load is likely to be thrown off.

VIII. MOTOR STOPS OR FAILS TO START.

This is an extreme case of the previous class ("Speed Too High or Too Low"), but is separated because it is more definite and permits of quicker diagnosis and treatment. This heading does not, of course, apply to generators, since any trouble in setting these in motion is usually outside of the machine itself.

CAUSE 1. Great overload.

A slight overload causes motor to run slowly, but an extreme overload will, of course, stop it entirely or "stall" it. (See "Sparking," Cause 1.)

SYMPTOM. On a constant-potential circuit the current is excessive, and safety-fuse blows or circuit-breaker opens. In their absence or failure, armature is burnt out.

REMEDY. Turn off switch instantly, reduce or take off the

load, replace the fuse or circuit-breaker, if necessary, and turn on current again just long enough to see if trouble still exists; if so, take off more load.

CAUSE 2. Very excessive friction due to shaft, bearings, or other parts being jammed, or armature touching pole pieces.

SYMPTOM. Similar to previous case, but distinguished from it by the fact that the armature is hard to turn even when load is taken off. Examination shows that the shaft is too large or is bent or rough, that the bearing is too tight, that the armature touches pole pieces, or that there is some other impediment to free rotation. (See "Heating of Bearings" and "Noise.")

REMEDY. Turn current off instantly, ascertain and remove the cause of friction, turn on the current again just long enough to see if trouble still exists; if so, investigate further.

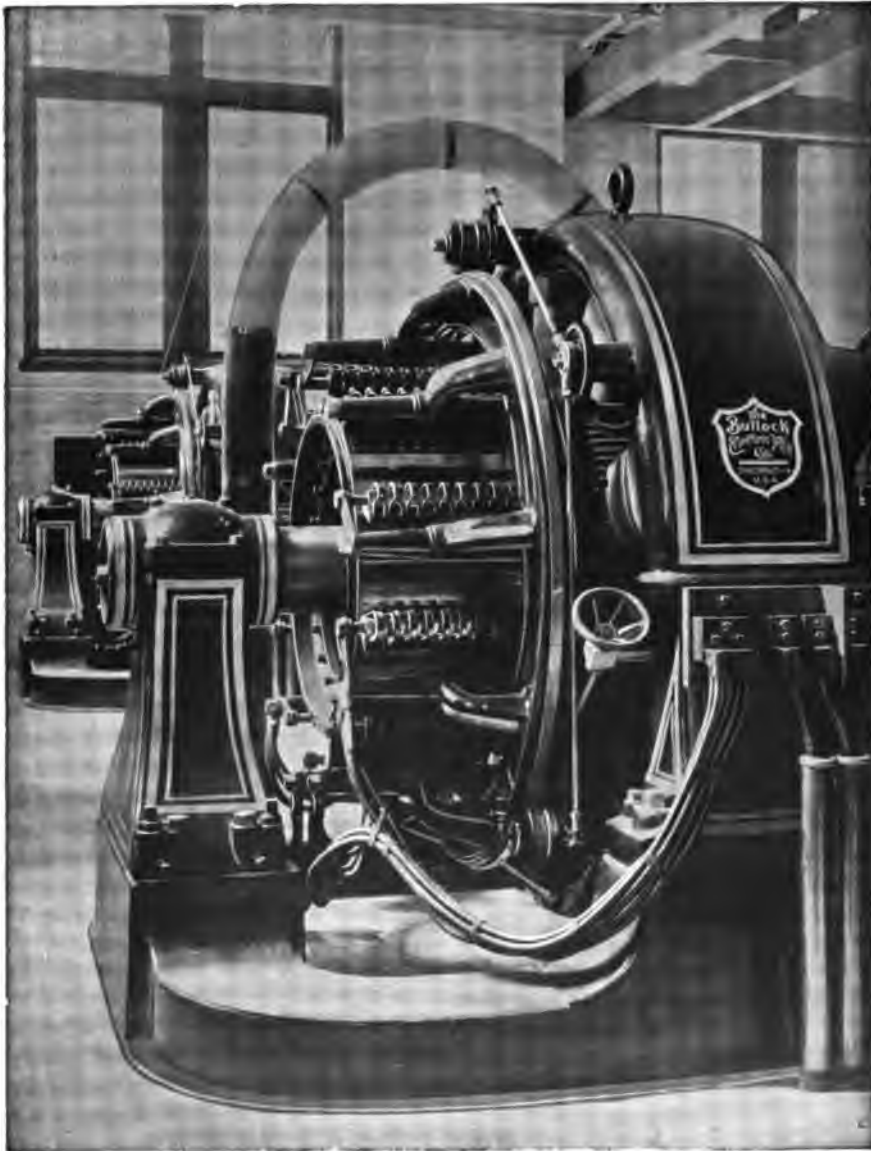
CAUSE 3. Circuit open.

This may be due to (a) safety-fuse blown or circuit-breaker open; (b) wire in motor broken or slipped out of connections; (c) brushes not in contact with commutator; (d) switch open; (e) circuit supplying motor open; (f) failure at generating plant.

SYMPTOM. Distinguished from causes 1 and 2 by the fact that if the load is taken off, the motor still refuses to start, and yet armature turns freely.

On a constant-potential circuit the field circuit alone of a shunt motor may be open, in which case the pole pieces are not strongly magnetic when tested with a piece of iron, and there is a dangerously heavy current in the armature; if the armature circuit is at fault, there is no spark when the brushes are lifted; and if both are without current, there is no spark when switch is opened. One should be very careful if there is no field magnetism or even if it is weak, as a motor is liable to be burnt out if the current is then thrown upon the armature.

REMEDY. Turn current off instantly. Examine safety-fuse circuit-breaker, wires, brushes, switch, and circuit generally, for break or fault. If none can be found, turn on switch again for a moment, as the trouble may have been due to a temporary stoppage of the current at the station or on the line. If motor still seems dead, test separately armature, field coils, and other parts of circuit for continuity with a magneto or a cell of battery and an electric



250 K.W. ENGINE-TYPE GENERATOR
at Prudential Life Building, Newark, N. J.
Bullock Electric Manufacturing Co.

bell, to see if there is any break in the circuit. (See "Instructions for Testing.")

One of the simplest ways to find whether the circuit has current on it and to locate any break, is to test through an incandescent lamp. Two or five lamps in series should be used on 220- and 500-volt circuits, respectively.

CAUSE 4. Wrong connection or complete short circuit of field, armature, switch, etc.

SYMPTOM. Distinguished from Causes 1 and 2 in the same way as Cause 3, and differs from Cause 3 in the evidence of strong current in motor.

On a constant-potential circuit, if current is very great, it indicates a short circuit. If the field is at fault, it will not be strongly magnetic.

The possible complications of wrong connections are so great that no exact rules can be given. Carefully examine and make sure of the correctness of all connections (see Diagrams of Connections). This trouble is usually inexcusable, since only a competent person should ever set up a machine or change its connections.

In the 3-wire (220-volt direct-current) system, several peculiar conditions may exist, as follows:

(a) The dynamo or dynamos on one side of the system may become reversed, so that both of the outside wires are positive or negative. In that case a motor fed in the usual way from the two outside conductors will get no current, but lamps connected between the neutral wire and either of the outside wires will burn as usual.

(b) If one of the outside wires is open by the blowing of a fuse, an accidental break, or other cause, then a motor (220-volt) beyond the break can get some current at 110 volts through any lamps that may be on the same side of the break as itself, and on the same side of the system as the conductor that is open. These lamps will light up when the motor is connected, but the motor will have little or no power unless the number of lamps is large.

(c) If the neutral or middle wire is open, a motor connected with the outside wires will run as usual; but lamps on one side of the system will burn more brightly than those on the other side, unless the two sides are perfectly balanced.

(*d*) If one of the outside wires becomes accidentally grounded, a 110-volt dynamo, motor, or other apparatus, also grounded and connected to the other outside wire, will receive 220 volts, which will probably burn it out.

IX. DYNAMO FAILS TO GENERATE.

This trouble is almost always caused by the inability of a dynamo to "excite" or "build up" its field-magnetism sufficiently. The proper starting of a self-exciting dynamo requires a certain amount of residual magnetism, which must be increased to full strength by the current generated in the machine itself. This trouble is not likely to occur in a separately-excited machine; and if it does it is usually due to the exciter failing to generate, and therefore amounts to the same thing.

CAUSE 1. Residual magnetism too weak or destroyed.

This may be due to (*a*) vibration or jar; (*b*) proximity of another dynamo; (*c*) earth's magnetism; (*d*) accidental reversed current through fields, not enough to completely reverse magnetism. The complete reversal of the residual magnetism in any dynamo will not prevent its generating, but will only make it build up of opposite polarity. Sometimes reversal of residual magnetism may be very objectionable, as in case of charging storage batteries; but, although the popular supposition is to the contrary, it will not cause the machine to fail to generate.

SYMPTOM. Little or no magnetic attraction when the pole pieces are tested with a piece of iron.

REMEDY. Send a magnetizing current from another machine or battery through the field coils, then start and try the machine; if this fails, apply the current in the opposite direction, since the magnets may have enough polarity to prevent the battery building them up in the direction first tried.

Shift the brushes backward in a generator, or forward in a motor to make armature magnetism assist field. Turn machine around or change its polarity, so that the magnetism which the earth or the adjacent machine tends to induce is in the right direction. Dynamos should be placed with their opposite poles toward each other, and the north pole of a machine should preferably be placed toward the north (which is magnetically the *south*

pole of the earth); but the earth's magnetism is hardly strong enough to reverse a dynamo's residual magnetism.

CAUSE 2. Reversed connections or reverse direction of rotation.

SYMPTOM. When running, pole pieces show no attraction for a piece of iron. The application of external current cannot be made to start the machine, as in case of Cause 1, because, whichever way the field may be magnetized, the resulting current generated by armature opposes and destroys the magnetism.

REMEDY. (*a*) Reverse either armature connections or field connections, *but not both*. (*b*) Move brushes through 180° for 2-pole, 90° for 4-pole machines, etc. (*c*) Reverse direction of rotation. After each of the above are tried, the field may have to be built up with a battery or other current, since the causes in this case operate to destroy whatever residual magnetism may have been present.

CAUSE 3. Short circuit in the machine or external circuit.

This applies to a shunt-wound machine, and has the effect of preventing the voltage and the field magnetism from building up.

SYMPTOM. Magnetism weak, but still quite perceptible.

REMEDY. If the short circuit is in the external circuit, opening the latter will allow the dynamo to build up and generate full voltage. If the short circuit is within the machine, it should be found by careful inspection or testing. In either of these cases, do not connect the external circuit until short circuit is found and eliminated. A slight short circuit, such as that caused by a defective lamp socket or by copper dust on the brush-holder or commutator, may prevent the magnetism of a shunt machine from building up. (See "Sparking," Causes 5 and 8.) Too many lamps, or other load, might prevent a shunt dynamo from building up its field magnetism, in which case the load should be disconnected in starting.

CAUSE 4. Field-coils opposed to each other.

SYMPTOM. Upon passing a current from another dynamo or a battery the following symptom will exist: If the pole-pieces of a bipolar machine are approached with a compass or other freely suspended magnet, they both attract the same end of the magnet,

showing them to be of the same polarity, whereas they should always be of opposite polarity.

For similar reasons the pole-pieces are magnetic when tested separately with a piece of iron, but show less attraction when the same piece of iron is applied to both at once, in which latter case the attraction should be stronger. In multipolar machines these tests should be applied to consecutive pole-pieces.

REMEDY. Reverse the connections of one of the coils in order to make the polarity of the pole-pieces opposite. The pole-pieces should be alternately north and south (when tested by compass).

CAUSE 5. Open circuit.

This may be due to (a) broken wire or faulty connection in machine; (b) brushes not in contact with commutator; (c) safety fuse melted or absent; (d) switch open; (e) external circuit open.

SYMPTOM. If the trouble is merely due to the switch or external circuit being open, the magnetism of a shunt dynamo may be at full strength, and the machine itself may be working perfectly; but if the trouble is in the machine, the field magnetism will probably be very weak.

REMEDY. Make very careful examination for open circuit; if not found, test separately the field-coils, armature, etc., for continuity, with magneto or cell of battery and electric bell. (See "Instructions for Testing;" also "Motor Stops," etc., Cause 3.)

A break, poor contact, or excessive resistance in the field circuit or regulator of a shunt dynamo will also make the magnetism weak and prevent its building up. This may be detected and overcome by cutting out the rheostat for a moment by connecting the two terminals of the field-coils to the two brushes respectively, care being taken not to make a short circuit.

A break or abnormally high resistance anywhere in the circuit of a series-wound dynamo will prevent it from generating, since the field-coil is in the main circuit. This may be detected and overcome by short-circuiting the machine for a moment in order to start up the magnetism.

Either of these two remedies by short-circuiting should be applied very carefully, and not until the pole-pieces have been tested with a piece of iron to make sure that the magnetism is weak.

CAUSE 6. Brushes not in proper position.

SYMPTOM. The magnetism and current are increased by shifting the brushes.

REMEDY. It often happens that the brushes are not set at the proper point; in fact, they may be set exactly wrong, so that the dynamo is incapable of generating any current whatever. This trouble is mainly due to the fact that the proper position for the brushes is not the same for all kinds of machines. Almost all ring armatures and many drum armatures require the brushes to be set opposite the *spaces* between the pole-pieces. But most armatures are wound so that the brushes must be set nearly 90° from this position, or opposite the center of the poles. Some multipolar machines have as many sets of brushes as there are pole pieces; while others have armatures that are cross-connected, or have the conductors arranged in series so that only two sets of brushes are required. Four-pole machines with only two brushes require them to be set at 90° ; 6-pole machines, either 60° or 180° ; 8-pole, either 45° or 135° ; 10-pole, either 36° , 108° , or 180° ; 12-pole, either 30° , 90° , or 150° ; and 16-pole, either $22\frac{1}{2}^\circ$, $67\frac{1}{2}^\circ$, $112\frac{1}{2}^\circ$, or $157\frac{1}{2}^\circ$; and so on.

The fact is, that the proper position of the brushes depends upon the particular winding, internal connections, etc., and *no one should ever assume to know where to set the brushes* unless he is perfectly familiar with the particular type of machine. A blue print or other definite instructions should always be obtained and followed; and, if these are not available, the matter may be determined by careful trial. The proper position of brushes is the same for dynamos and motors, except that in the former the brushes are given a forward lead, that is, shifted a little in the direction of rotation, whereas motor brushes should be set a little backward. This shifting is necessitated by the armature reaction or the magnetizing effect of the armature current, which distorts the field magnetism.

The positions and number of brushes for each kind of armature are shown in Fig. 67, which shows also the arrangements of circuits in each of the leading types.

A is the armature for the ordinary two-pole machine, and may be drum- or ring-wound. The current enters from the positive

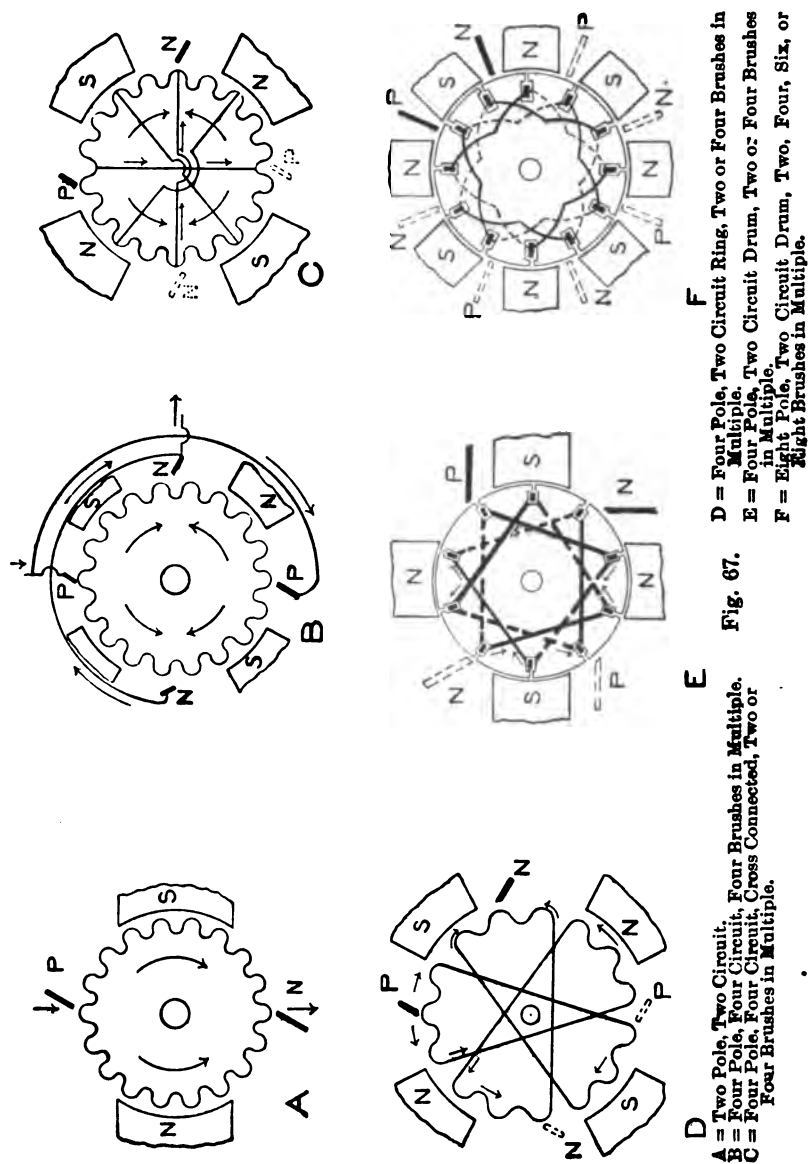


Fig. 67.

brush, passes around both sides of the armature, and out through the negative brush. Hence this is called a "two-circuit" armature.

B is a plain armature used in a 4-pole machine. As there are here two more poles, it is necessary to use two more brushes to collect the current. This gives two brushes through which current enters, and two through which it leaves; consequently each pair of brushes must be joined in multiple in order to carry all the current to the mains.

C is a 4-pole armature in which the additional currents are carried across to the first pair of brushes by means of connections through the center of the armature. Therefore, the entire current may be taken off by these brushes; or two more may be added to divide the work, in which case they must also be connected in multiple to the first pair, as in case B above.

With either B or C, since there are two parts of the armature winding under the influence of different magnets, but running in parallel to the mains, it is evident that if the pressure of the current in one part of the winding is weaker than in the other, through inequality of the magnets or otherwise, it will short-circuit the other part of the winding and work badly.

This cannot occur in A, because both parts of the winding are influenced by the two ends of a single magnet.

D is a 4-pole armature in which the windings do not connect together in parallel but *in series*, thus overcoming the objection above. It has a ring-winding, and each coil is connected to the one diametrically opposite. An examination will show that though the poles alternate, the wire is all arranged so that the current flows in a single pair of circuits, as in A. This also permits of the use of larger wire and fewer turns, as they are connected in series instead of multiple.

E is a drum armature all in series, as in the case of D. Inspection will show that the actions of each of the four poles on all the bars harmonize, or cause the current to flow in the same direction.

To facilitate tracing the course of the current, the arrangement is represented with the smallest possible number of bars. Many more are used in practice.

F is a series drum armature for eight poles. The principle is the same, but the limit of brush adjustment is smaller. The entire range from zero to full E. M. F. is covered by moving the brush one-eighth of the circumference.

As the winding is all in series, two brushes only are necessary; but as many more as desired may be added between the other poles, and then connected in multiple to the first ones. This is usually taken advantage of, because a single pair of brushes would become heated from carrying excessive current; but the difficulty of one part of the armature short-circuiting the other cannot occur, because *each part* of the winding is under the influence of all the poles.

X. VOLTAGE OF GENERATOR NOT RIGHT

VOLTAGE TOO LOW.

CAUSE 1. **Speed too low.** (See "Speed not Right.")

REMEDY. Increase speed of the prime mover, if possible; when this cannot be done, decrease the diameter of the driven pulley or increase the diameter of the driving pulley, preferably the latter.

CAUSE 2. **Field magnetism weak.**

SYMPTOM AND REMEDY. (See "Sparking," Cause 8.)

CAUSE 3. **Brushes not in proper position.**

SYMPTOM AND REMEDY. (See "Sparking," Cause 2.)

CAUSE 4. **Machine overloaded.**

SYMPTOM AND REMEDY. (See "Sparking," Cause 1 and "Speed not Right," Cause 1); also increase field excitation, if possible.

CAUSE 5. **Short-circuited armature coil or coils.**

SYMPTOM AND REMEDY. (See "Sparking," Cause 5.)

CAUSE 6. **Reversed armature coil or coils.**

SYMPTOM AND REMEDY. (See "Sparking," Cause 5.)

VOLTAGE TOO HIGH.

CAUSE 7. **Speed too high.**

REMEDY. Apply the reverse of treatment given in Cause 1.

CAUSE 8. **Field magnetism too powerful.**

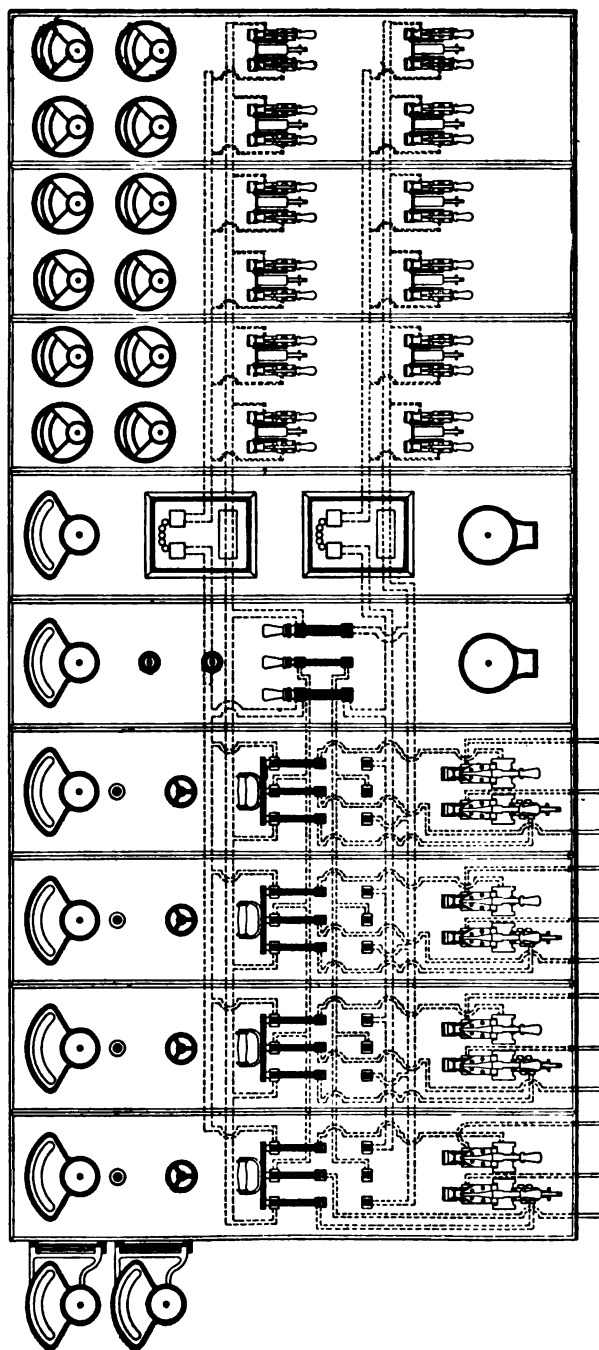
REMEDY. Increase resistance of shunt field circuit, by means of a shunt field rheostat.

CAUSE 9. Machine Compounds too much.

REMEDY. Decrease resistance of series field shunt.

(See Compound-wound Dynamos, page 25, Part I.)

SWITCHBOARD FOR A MANUFACTURING PLANT
SHOWING USE OF OIL-BREAK-CIRCUIT BREAKERS



SWITCHBOARD.
The Cutter Company

ELECTRIC WIRING

METHODS OF WIRING

The different methods of wiring which are now approved by the National Board of Fire Underwriters, may be classified under four general heads, as follows:

1. WIRES RUN CONCEALED IN CONDUITS.
2. WIRES RUN IN MOULDING.
3. CONCEALED KNOB AND TUBE WIRING.
4. WIRES RUN EXPOSED ON INSULATORS.

WIRES RUN CONCEALED IN CONDUITS

Under this general head, will be included the following:

- (a) Wires run in rigid conduits.
- (b) Wires run in flexible metal conduits.
- (c) Armored cable.

Wires Run in Rigid Conduit. The form of rigid metal conduit now used almost exclusively, consists of plain iron gaspipe the interior surface of which has been prepared by removing the scale and by removing the irregularities, and which is then coated with flexible enamel. The outside of the pipe is given a thin coat of enamel in some cases, and, in other cases, is galvanized. Fig. 1 shows one make of enameled (unlined) conduit.



Fig. 1. Rigid Enameled Conduit, Unlined.
Courtesy of American Conduit Mfg. Co., Pittsburg, Pa.

Another form of rigid conduit is that known as the *armored conduit*, which consists of iron pipe with an interior lining of paper impregnated with asphaltum or similar compound. This latter form of conduit is now rapidly going out of use, owing to the unlined pipe being cheaper and easier to install, and owing also to improved methods of protecting the iron pipe from corrosion, and to the introduction of additional braid on the conductors, which partly compensates for the

pipe being unlined. The introduction of improved devices—such as outlet insulators, for protecting the conductors from the sharp edges of the pipe, at outlets, cut-out cabinets, etc.—also decreases the necessity of the additional protection afforded by the interior paper lining.

Rigid conduits are made in gaspipe sizes, from one-half inch to three inches in diameter. The following table gives the various data relating to rigid, enameled (unlined) conduit:

TABLE I
Rigid, Enameled Conduit—Sizes, Dimensions, Etc.

STANDARD PIPE SIZE	THICKNESS	NOMINAL WEIGHT PER 100 FEET	NUMBER OF THREADS PER INCH OF SCREW	ACTUAL OUTSIDE DIAMETER, INCHES	NOMINAL INSIDE DIAMETER, INCHES
$\frac{1}{2}$	.109	84	14	.84	.62
$\frac{3}{4}$	.113	112	14	1.05	.82
1	.134	167	11 $\frac{1}{2}$	1.31	1.04
1 $\frac{1}{4}$	.140	224	11 $\frac{1}{2}$	1.66	1.38
1 $\frac{1}{2}$	.145	268	11 $\frac{1}{2}$	1.90	1.61
2	.154	361	11 $\frac{1}{2}$	2.37	2.06
2 $\frac{1}{2}$	.204	574	8	2.87	2.46
3	.217	754	8	3.50	3.06

Tables II, III, and IV give the various sizes of conductors that may be installed in these conduits. Caution must be exercised in

TABLE II
Single Wire in Conduit

SIZE WIRE, B. & S. G.	LORICATED CONDUIT, UNLINED; D. B. WIRE
No. 14-4	$\frac{1}{2}$ inch
" 2	$\frac{3}{4}$ "
" 1	$\frac{1}{2}$ "
" 0	$\frac{3}{4}$ inch or 1 "
" 00	1 "
" 000	1 "
" 0000	1 "
250,000 C. M.	1 $\frac{1}{2}$ "
300,000 C. M.	1 $\frac{1}{2}$ "
350,000 C. M.	1 $\frac{1}{2}$ "
400,000 C. M.	1 $\frac{1}{2}$ " or 1 $\frac{1}{2}$ "
450,000 C. M.	1 $\frac{1}{2}$ "
500,000 C. M.	1 $\frac{1}{2}$ "
600,000 C. M.	1 $\frac{1}{2}$ " or 2 "
700,000 C. M.	2 "
800,000 C. M.	2 "
900,000 C. M.	2 "
1,000,000 C. M.	2 " or 2 $\frac{1}{2}$ "
1,500,000 C. M.	2 $\frac{1}{2}$ "
1,700,000 C. M.	3 "
2,000,000 C. M.	3 "

TABLE III
Two Wires in One Conduit

SIZE WIRE, B. & S. G.	LORICATED CONDUIT, UNLINED; D. B. WIRE
No. 14	$\frac{1}{2}$ inch or $\frac{3}{4}$ inch.
" 12	$\frac{3}{4}$ " "
" 10	$\frac{3}{4}$ " "
" 8	1 " "
" 6	1 " "
" 5	1 " or $1\frac{1}{4}$ " "
" 4	$1\frac{1}{4}$ " "
" 3	$1\frac{1}{4}$ " "
" 2	$1\frac{1}{4}$ " or $1\frac{3}{4}$ " "
" 1	$1\frac{3}{4}$ " "
" 0	$1\frac{3}{4}$ " "
" 00	$1\frac{3}{4}$ " or 2 " "
" 000	2 " "
" 0000	2 " "
250,000 C. M.	2 " or $2\frac{1}{2}$ " "
300,000 C. M.	$2\frac{1}{2}$ " "
350,000 C. M.	$2\frac{1}{2}$ " "
400,000 C. M.	$2\frac{1}{2}$ " or 3 " "
450,000 C. M.	3 " "
500,000 C. M.	3 " "
600,000 C. M.	3 " "
700,000 C. M.	3 " "

TABLE IV
Three Wires in One Conduit

SIZE WIRE, B. & S. G.		LORICATED TUBE, UNLINED; D. B. WIRE
Outside	Center	
No. 14	No. 12	$\frac{3}{4}$ inch
" 12	" 10	$\frac{3}{4}$ " "
" 10	" 8	1 " "
" 8	" 6	1 " "
" 6	" 4	$1\frac{1}{4}$ " "
" 5	" 2	$1\frac{1}{4}$ " "
" 4	" 1	$1\frac{1}{4}$ " or $1\frac{3}{4}$ " "
" 3	" 0	$1\frac{3}{4}$ " "
" 2	" 2/0	$1\frac{3}{4}$ " or 2 " "
" 1	" 3/0	2 " "
" 0	" 4/0	2 " "
" 2/0	250 M.	2 " or $2\frac{1}{2}$ " "
" 3/0	300 M.	$2\frac{1}{2}$ " "
" 4/0	400 M.	$2\frac{1}{2}$ " "
250 M.	450 M.	$2\frac{1}{2}$ " or 3 " "
250 M.	500 M.	3 " "
300 M.	600 M.	3 " "
350 M.	700 M.	3 " "
400 M.	800 M.	3 " "
450 M.	900 M.	3 " "

using these tables, for the reason that the sizes of conductors which may be safely installed in any run of conduit depend, of course, upon the length of and the number of bends in the run. The tables are based on average conditions where the run does not exceed 90 to 100 feet, without more than three or four bends, in the case of the smaller sizes of wires for a given size of conduit; and where the run does not exceed 40 to 50 feet, with not more than one or two bends, in the case of the larger sizes of wires, for the same sizes of conduit.

Unlined conduit can be bent without injury to the conduit, if the conduit is properly made and if proper means are used in making the bends. Care should be exercised to avoid flattening the tube as a result of making the bend over a sharp curve or angle.

In installing iron conduits, the conduits should cross sleepers or beams at right angles, so as to reduce the amount of cutting of the beams or sleepers to a minimum.

Where a number of conduits originate at a center of distribution, they should be run at right angles for a distance of two or three feet from the cut-out box, in order to obtain a symmetrical and workman-like arrangement of the conduits, and so as to have them enter the cabinet in a neat manner. While it is usual to use red or white lead at the joints of conduits in order to make them water-tight, this is frequently unnecessary in the case of enameled conduit, as there is often sufficient enamel on the thread to make a water-tight joint.

When iron conduits are installed in ash concrete, in Keene cement, or, in general, where they are subject in any way to corrosive action, they should be coated with asphaltum or other similar protective paint to prevent such action.

While the cost of circuit work run in iron conduits is usually greater than any other method of wiring, it is the most permanent and durable, and is strongly recommended where the first cost is not the sole consideration. This method of wiring should always be used in fireproof buildings, and also in the better class of frame buildings. It is also to be recommended for exposed work where the work is liable to disturbance or mechanical damage.

Wires Run in Flexible Metal Conduit. This form of conduit, shown in Fig. 2, is described by the manufacturers as a conduit composed of "concave and convex metal strips wound spirally upon each other in such a manner as to interlock several concave surfaces and

present their convex surfaces, both exterior and interior, thereby securing a smooth and comparatively frictionless surface inside and out."

The field for the use of this form of conduit is rapidly increasing. Owing to its flexibility, conduit of this type can be used in numerous cases where the rigid conduit could not possibly be employed. Its use is to be recommended above

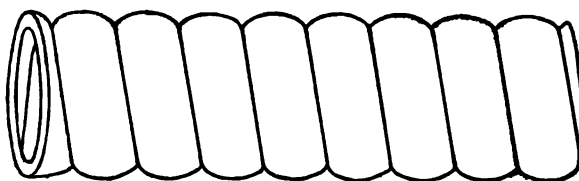


Fig. 2. Flexible Steel Conduit.
Courtesy of Sterling Electric Co., Troy, N. Y.

all the other forms of wiring, except that installed in rigid conduits. For new fireproof buildings, it is not so durable as the rigid conduit, because not so water-tight; and it is very difficult, if not impossible, to obtain as workmanlike a conduit system with the flexible as with the rigid type of conduit. For completed or old frame buildings, however, the use of the flexible conduit is superior to all other forms of wiring.

Table V gives the inside diameter of various sizes of flexible conduit, and the lengths of standard coils. The inside diameter of this conduit is the same as that of the rigid conduit; and the table given for the maximum sizes of conductors which may be installed in the various sizes of conduits, may be used also for flexible steel conduits, except that a little more margin should be allowed for flexible steel conduits than for the rigid conduits, as the stiffness of the latter makes it possible to pull in slightly larger sized conductors.

TABLE V
Greenfield Flexible Steel Conduit

INSIDE DIAMETER	APPROXIMATE FEET IN COIL
$\frac{3}{8}$ inch	200
$\frac{1}{2}$ "	200
$\frac{5}{8}$ "	100
$\frac{3}{4}$ "	50
1 "	50
$1\frac{1}{4}$ inches	50
$1\frac{1}{2}$ "	50
2 "	Random Lengths
$2\frac{1}{2}$ "	" "
3 "	" "

This conduit should, of course, be first installed without the conductors, in the same manner as the rigid conduit. Owing to the flexibility of this conduit, however, it is absolutely essential to fasten it securely at all elbows, bends, or offsets; for, if this is not done, considerable difficulty will be experienced in drawing the conductors in the conduit.

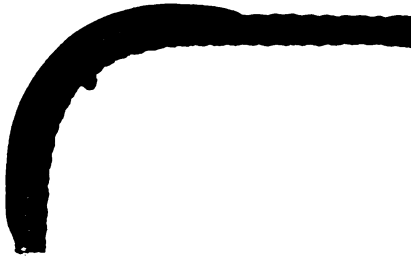


Fig. 3. Use of Elbow Clamp for Fastening Flexible Conduit in Place.

considerable difficulty will be experienced in drawing the conductors in the conduit.

The rules governing the installation of this conduit are the same as those covering rigid conduits. Double-braided conductors are required, and the conduit should be grounded

as required by the *Code Rules*. As already stated, the conduit should be securely fastened (in not less than three places) at all elbows; or else the special elbow clamp made for this purpose, shown in Fig. 3, should be used.

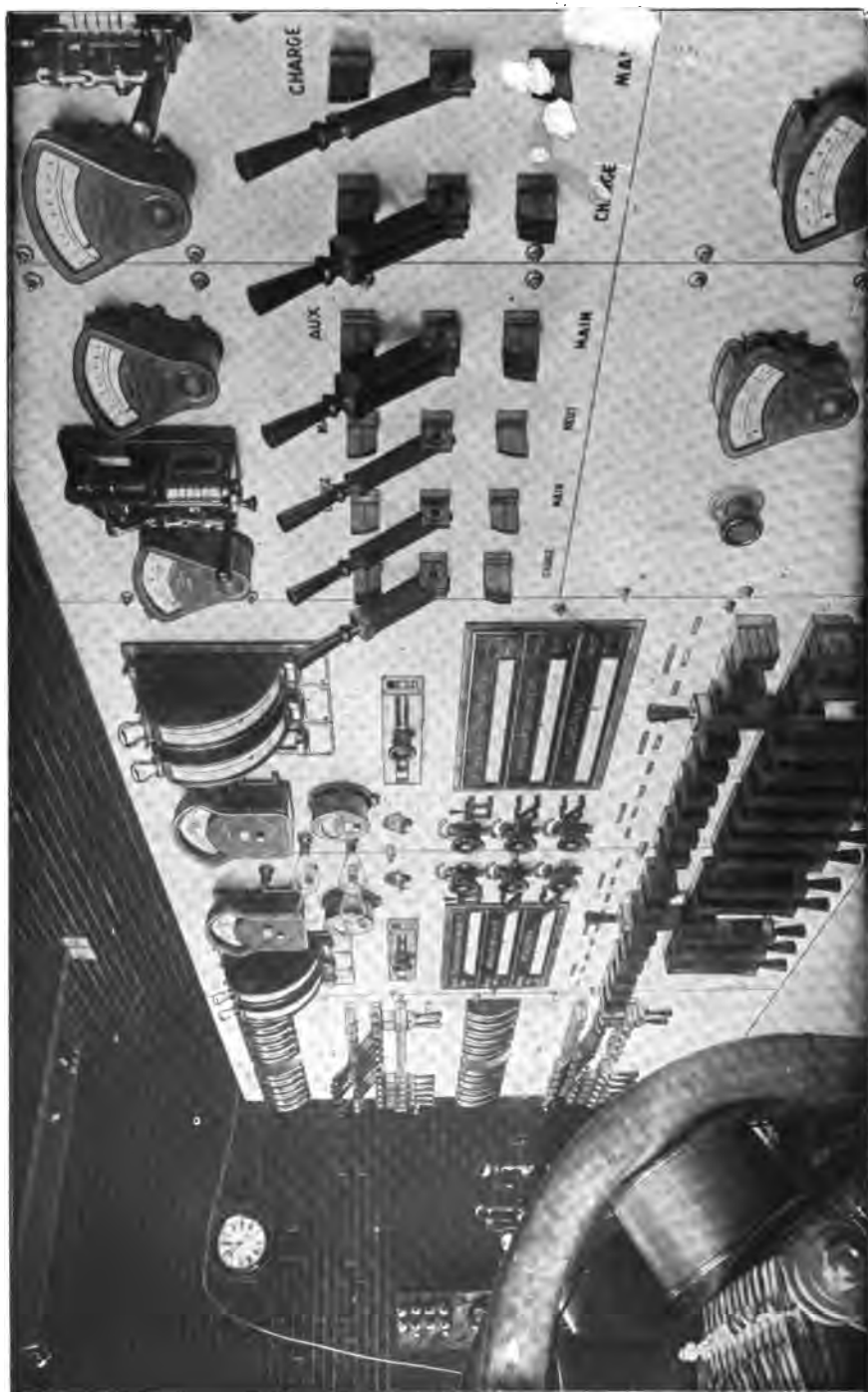
In order to cut flexible steel conduit properly, a fine hack saw should be employed. Outlet-boxes are required at all outlets, as well as bushing and wires to rigid conduit. Fig. 4 shows a coil of flexible steel conduit. Figs. 5, 6, and 7 show, respectively, an outlet box and cover, outlet plate, and bushing used for this conduit.

Armored Cable. There are many cases where it is impossible to install a conduit system. In such cases, probably the next best results may be obtained by the use of *steel armored cable*. The rules governing the installation of armored cable are given in the *National Electric Code*, under Section 24-A, and Section 48; also in 24-S. This cable is shown in Fig. 8.



Fig. 4. A 100-Foot Coil of Flexible Steel Conduit. Courtesy of Sprague Electric Co., New York, N.Y.

Steel armored cable is made by winding formed steel strips over the insulated conductors. The steel strips are similar to those used



Storage Battery Switchboard
Detroit Edison Company

for the steel conduit. Care is taken in forming the cable, to avoid crushing or abraiding the insulation on the conductors as the steel



Fig. 5. Outlet Box for Flexible Steel Conduit.

strips are fed and formed over the same. In the process of manufacture, the spools of steel ribbon are of irregular length, and when a



Fig. 6. Outlet Plate for Flexible Steel Conduit.



Fig. 7. Outlet Bushing.
Courtesy of Sprague Electric Co., New York, N. Y.

spool is empty, the machine is stopped, and the ribbon is started on the next spool, the process being continued. There is no reason why



Fig. 8. Flexible Armored Cable. Twin Conductors.
Courtesy of Sprague Electric Co., New York, N. Y.

the conduit cables could not be made of any length; but their actual lengths as made are determined by convenience in handling. Armored

cable is made in *single conductors* from No. 1 to No. 10 B. & S. G.; in *twin conductors*, from No. 6 to No. 14 B. & S. G.; and *three-conductor* cable, from No. 10 to No. 14 B. & S. G. Table VI gives various data relating to armored conductors:

TABLE VI
Armored Conductors—Types, Dimensions, Etc.

SIZE B. & S. GAUGE	TYPE AND NUMBER OF CONDUCTORS	OUTSIDE DIAMETER (INCHES)
No. 14	BX twin conductor	.63
" 12	" " "	.685
" 10	" " "	.725
" 8	" " "	.875
" 6	" " "	1.3125
" 14	BM twin conductor (for marine work—ship wiring)	.725
" 12	" " "	.725
" 10	" " "	.73
" 14	BX3 three conductor	.71
" 12	" " "	.725
" 10	" " "	.73
" 14	BXL twin conductor, leaded	.725
" 12	" " "	.725
" 10	" " "	.87
" 14	BXL3 three conductor, leaded	.90
" 12	" " "	.90
" 10	" " "	.94
" 10	Type D single conductor, stranded	.550
" 8	" " " " "	.550
" 6	" " " " "	.575
" 4	" " " " "	.700
" 2	" " " " "	.900
" 1	" " " " "	.965
" 10	Type DL single conductor, stranded, leaded	.625
" 8	" " " " "	.710
" 6	" " " " "	.700
" 4	" " " " "	.760
" 2	" " " " "	.920
" 1	" " " " "	.910
STEEL ARMORED FLEXIBLE CORD		
" 18	Type E twin conductor	.40
" 16	" " " "	.40
" 14	" " " "	.47
" 18	Type EM twin conductor, re-inforced	.575
" 16	" " " "	.585
" 14	" " " "	.595

In Table VI, Types D (single), BX (twin), and BX3 (3 conduc-

tors) are armored cable adapted for ordinary indoor work. Type BM (twin conductors) is adapted for marine wiring. Types DL (single), BXL (twin), and BXL 3 (3 conductors) have the conductors lead-encased, with the steel armor outside, and are especially adapted for damp places, such as breweries, stables, and similar places.

Type E is used for flexible-cord pendants, and is suitable for factories, mills, show windows, and other similar places. Type EM is the same as Type E; but the flexible cord is reinforced, and is suitable for marine work, for use in damp places, and in all cases where it will be subject to very rough handling.

While this form of wiring has not the advantage of the conduit system—namely, that the wires can be withdrawn and new wires inserted without disturbing the building in any way whatever—yet it has many of the advantages of the flexible steel conduit, and it has some additional advantages of its own. For example, in a building already erected, this cable can be fished between the floors and in the partition walls, where it would be impossible to install either rigid conduit or flexible steel conduit without disturbing the floors or walls to an extent that would be objectionable.

Armored conductors should be continuous from outlet to outlet, without being spliced and installed on the loop system. Outlet boxes should be installed at all outlets, although, where this is impossible, outlet plates may be used under certain conditions. Clamps should be provided at all outlets, switch-boxes, junction-boxes, etc., to hold the cable in place, and also to serve as a means of grounding the steel sheathing.

Armored cable is less expensive than the rigid conduit or the flexible steel conduit, but more expensive than cleat wiring or knob and tube wiring, and is strongly recommended in preference to the latter.

WIRES RUN IN MOULDING

Moulding is very extensively used for electric circuit work, in extending circuits in buildings which have already been wired, and also in wiring buildings which were not provided with electric circuit work at the time of their erection. The reason for the popularity of moulding is that it furnishes a convenient and fairly good-looking runway for the wires, and protects them from mechanical injury.

It seems almost unwise to place conductors carrying electric current, in wood casing; but this method is still permitted by the *National Electric Code*, although it is not allowed in damp places or in places

where there is liability to dampness, such as on brick walls, in cellars, etc.

The dangers from the use of moulding are that if the wood becomes soaked with water, there will be a liability to leakage of current between the conductors run in the grooves of the moulding, and to fire being thereby started, which may not be immediately discovered.

Furthermore, if the conductors are overloaded, and consequently overheated, the wood is likely to become charred and finally ignited. Moreover, the moulding itself is always a temptation as affording a good "round strip" in which to drive nails, hooks, etc. However, the convenience and popularity of moulding cannot be denied; and until some better substitute is found, or until its use is forbidden by the *Rules*, it will continue to be used to a very great extent for running circuits outside of the walls and on the ceilings of existing buildings. Figs. 9, 10, 11, and 12 show two- and three-wire moulding respectively; and Table VII gives complete data as to sizes of the moulding required for various sizes of conductors.

While the *Rules* recommend the use of hardwood moulding, as a matter of fact probably 90 per cent of the moulding used is of white-wood or other similar cheap, soft wood. Georgia pine or oak ordinarily

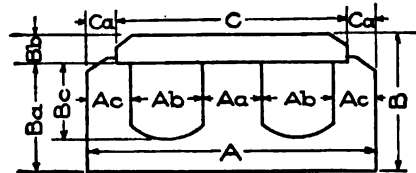


Fig. 9. Two-Wire Wood Moulding.

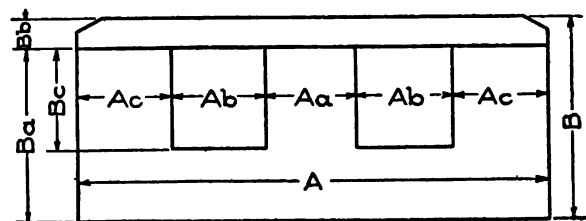


Fig. 10. Two-Wire Wood Moulding.

costs about twice as much as the soft wood. In designing moulding work, if appearance is of importance, the moulding circuits should be laid out so as to afford a symmetrical and complete design. For

example, if an outlet is to be located in the center of the ceiling, the moulding should be continued from wall to wall, the portion beyond the outlet, of course, having no conductors inside of the moulding. If four outlets are to be placed on the ceiling, the rectangle of moulding should be completed on the fourth side, although, of course, no con-

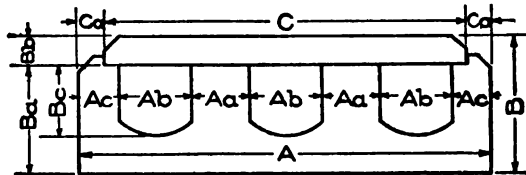


Fig. 11. Three-Wire Wood Moulding.

ductors need be placed in this portion of the moulding. Doing this increases the cost but little and adds greatly to the appearance.

Moulding is frequently used in combination with other methods of wiring, including armored cable, flexible steel tubing, and fibrous tubing. In many instances, it is possible to fish tubing between beams or studs running in a certain direction; but when the conductors are to run in another direction or at right angles to the beams or studs, exposed work is necessary. In such cases, a junction-box or outlet-box must be placed at the point of connection between the moulding and the armored cable or steel tubing.

Where circuits are run in moulding, and pass through the floor, additional protection must be provided, as required by the *Code Rules*,

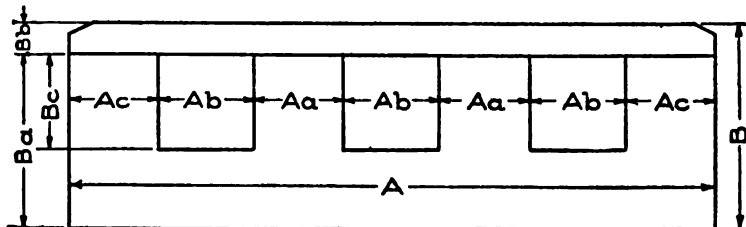


Fig. 12. Three-Wire Wood Moulding.

to protect the moulding. As a rule, it is better to use conduit for all portions of moulding within six feet of the floor, so as to avoid the possibility of injury to the circuits. Where a combination of iron conduit or flexible steel tubing is used with moulding, it is well to use double-braided conductors throughout, because, although only single-

TABLE VII
Sizes of Mouldings Required for Various Sizes of Conductors

FIG. NO.	TYPE OF Moulding	NUMBER OF WIRES	MAXIMUM SIZE OF WIRE BAND S. GAUGE		DIMENSIONS IN INCHES									
			SOLID	STRANDED	A	Aa	Ab	Ac	B	Ba	Bb	Bc	C	Ca
9	A-2	2	12	14	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{27}{32}$	$\frac{5}{8}$	$\frac{7}{32}$	$\frac{1}{4}$	$\frac{1}{8}$	$\frac{3}{16}$
9	A-4	2	8	10	$\frac{11}{16}$	$\frac{1}{2}$	$\frac{5}{16}$	$\frac{9}{32}$	$\frac{29}{32}$	$\frac{11}{16}$	$\frac{7}{32}$	$\frac{5}{16}$	$\frac{15}{16}$	$\frac{3}{16}$
9	A-6	2	4	5	2	$\frac{1}{2}$	$\frac{7}{16}$	$\frac{5}{16}$	$\frac{11}{16}$	$\frac{13}{16}$	$\frac{1}{4}$	$\frac{7}{16}$	$\frac{9}{16}$	$\frac{7}{32}$
9	A-8	2	1	2	$2\frac{3}{8}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{3}{8}$	$\frac{13}{16}$	$\frac{15}{16}$	$\frac{1}{4}$	$\frac{9}{16}$	$\frac{13}{16}$	$\frac{9}{32}$
9	A-9	2	—	$3/0$	3	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{16}$	$\frac{13}{32}$	$\frac{1}{8}$	$\frac{9}{32}$	$\frac{3}{4}$	$2\frac{7}{16}$	$\frac{9}{32}$
10	A-10	2	—	250000 C.M.	$3\frac{15}{16}$	$\frac{11}{16}$	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{11}{16}$	$\frac{3}{8}$	$\frac{5}{16}$	$\frac{7}{8}$	—	—
10	A-11	2	—	400000 C.M.	$4\frac{7}{8}$	$\frac{15}{16}$	1	$\frac{31}{32}$	$2\frac{3}{16}$	$\frac{1}{8}$	$\frac{5}{16}$	1	—	—
11	B-2	3	12	14	$2\frac{3}{16}$	$\frac{7}{16}$	$\frac{1}{4}$	$\frac{9}{32}$	$\frac{27}{32}$	$\frac{5}{8}$	$\frac{7}{32}$	$\frac{1}{4}$	$\frac{13}{16}$	$\frac{3}{16}$
11	B-4	3	8	10	$2\frac{1}{2}$	$\frac{15}{32}$	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{29}{32}$	$\frac{11}{16}$	$\frac{7}{32}$	$\frac{5}{16}$	$2\frac{1}{8}$	$\frac{3}{16}$
11	B-6	3	4	5	$2\frac{7}{8}$	$\frac{13}{32}$	$\frac{7}{16}$	$\frac{3}{8}$	$\frac{11}{16}$	$\frac{13}{16}$	$\frac{1}{4}$	$\frac{7}{16}$	$2\frac{3}{8}$	$\frac{1}{4}$
11	B-8	3	1	2	$3\frac{5}{8}$	$\frac{19}{32}$	$\frac{9}{16}$	$\frac{3}{8}$	$\frac{13}{16}$	$\frac{15}{16}$	$\frac{1}{4}$	$\frac{9}{16}$	$3\frac{1}{16}$	$\frac{9}{32}$
11	B-9	3	—	$3/0$	$4\frac{5}{16}$	$\frac{9}{16}$	$\frac{3}{4}$	$\frac{15}{32}$	$\frac{13}{32}$	$\frac{1}{8}$	$\frac{9}{32}$	$\frac{3}{4}$	$3\frac{3}{4}$	$\frac{9}{32}$
12	B-10	3	—	250000 C.M.	$5\frac{1}{2}$	$\frac{23}{32}$	$\frac{7}{8}$	$\frac{23}{32}$	$\frac{11}{16}$	$\frac{3}{8}$	$\frac{5}{16}$	$\frac{7}{8}$	—	—
12	B-11	3	—	400000 C.M.	$6\frac{3}{4}$	$\frac{15}{16}$	1	$\frac{15}{16}$	$2\frac{3}{16}$	$\frac{1}{8}$	$\frac{5}{16}$	1	—	—

braided conductors are required with moulding, double-braided conductors are required with unlined conduit, and if double-braided conductors were not used throughout, it would be necessary to make a joint at the outlet-box where the moulding stopped and the conduit work commenced. Where the conductors pass through floors, in moulding work, and where iron conduit is used, the inspection authorities, in order to protect the wire, usually require that a fibrous tubing be used as additional protection for the conductors inside of the iron pipe, although, if double-braided wire is used, this will not usually be required. Fig. 13 shows a fuseless cord rosette for use with moulding work. Fig. 14 shows a device for making a *tap* in moulding wiring.

Moulding work, under ordinary conditions, costs about one-half as much as circuit run in rigid conduit, and about 75 per cent, under

ordinary conditions, of the cost of armored cable. Where the latter method of wiring or the conduit system can be employed, one or the other of these two methods should be used in preference to moulding,

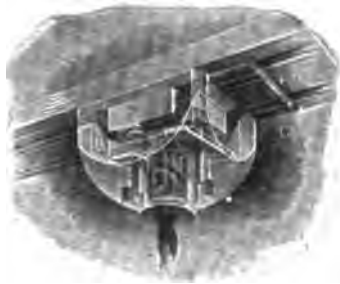


Fig. 13. Fuseless Cord
Rosette.
*Courtesy of Crouse-Hinds Co.,
Syracuse, N. Y.*



Fig. 14. Device for Making "Tap" in
Moulding.
*Courtesy of H. T. Poole Co.,
Philadelphia, Pa.*

as the work is not only more substantial, but also safer. Various forms of metal moulding have been introduced, but up to the present time have not met with the success which they deserve.

CONCEALED KNOB AND TUBE WIRING

This method of wiring is still allowed by the *National Electric Code*, although many vigorous attempts have been made to have it abolished. Each of these attempts has met with the strongest opposition from contractors and central stations, particularly in small towns and villages, the argument for this method being, that it is the cheapest method of wiring, and that if it were forbidden, many places which are wired according to this method would not be wired at all, and the use of electricity would therefore be much restricted, if not entirely done away with, in such communities. This argument, however, is only a temporary makeshift obstruction in the way of inevitable progress, and in a few years, undoubtedly, the concealed knob and tube method will be forbidden by the *National Electric Code*.

The cost of wiring according to this method is about one-third of the cost of circuits run in rigid conduit, and about one-half of the cost of circuits run in armored cable. The latter method of wiring

is rapidly replacing knob and tube wiring, and justly so, wherever the additional price for the latter method of wiring can be obtained. As the name indicates, this method of wiring employs *porcelain knobs*

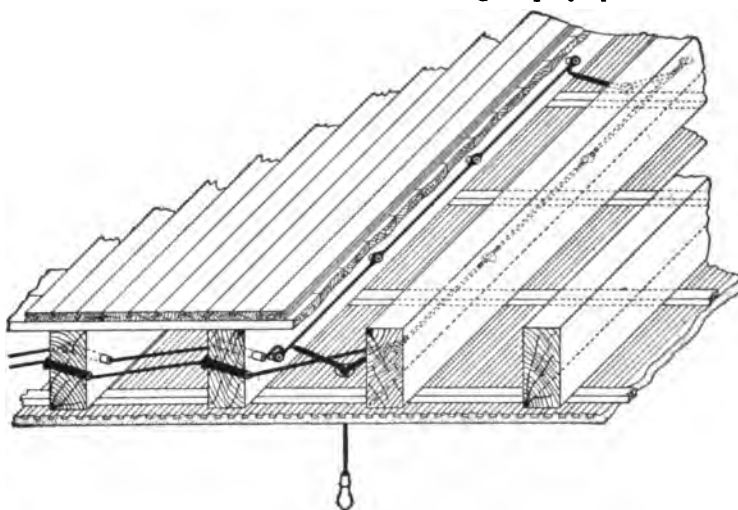


Fig. 15. Knob and Tube Wiring.

and tubes, the circuit work being run *concealed* between the floor beams and studs of a frame building. The knobs are used when the circuits run parallel to the floor beams; and the porcelain tubes are used when the circuits are run at right angles to the floor beams.

Fig. 15 shows an example of knob and tube wiring. In concealed knob and tube wiring, the wires must be separated at least ten inches from one another, and at least one inch from the surface wired over, that is, from the beams, flooring, etc., to which the insulator is fastened.

Fig. 16 shows a good type of porcelain knob for this class of wiring. For knob and tube wiring, it will be noted that, owing to the fact that the wiring is concealed, the conductors

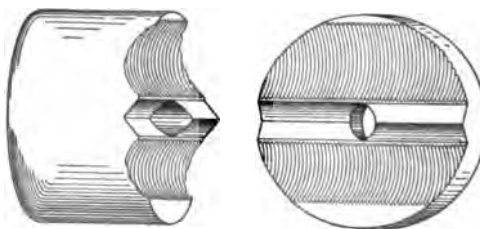


Fig. 16. Porcelain Knob.

must be kept further apart than in the case of exposed or open wiring on insulators, where, except in damp places, the wires may be run on cleats or on insulators only one-half inch from the surface wired over.

Fibrous Tubing. Fibrous tubing is frequently used with knob and tube wiring, and the regulations governing its use are given in Rule 24, Section S, of the *National Electric Code*. This tubing, as stated in this *Rule*, may be used where it is impossible and impracticable to employ knobs and tubes, provided the difference in potential between the wires is not over 300 volts, and if the wires are not sub-



Fig. 17. Flexible Tubing, "Flexduct" Type.
Courtesy of National Metal Molding Co., Pittsburgh, Pa.

ject to moisture. The cost of wiring in flexible fibrous tubing is approximately about the same as the cost of knob and tube wiring. Duplex conductors, or two wires together are not allowed in fibrous tubing.

Fibrous tubing is required at all outlets where conduit or armored cable is not used (as in knob and tube wiring); and, as required by the *Rules*, it must extend back from the last porcelain support to one inch beyond the outlet. Fig. 17 shows one make of fibrous tubing.

Table VIII gives the maximum sizes of conductors (double-braided) which may be installed in fibrous conduit.

TABLE VIII
Sizes of Conductors in Fibrous Conduit

OUTSIDE DIAMETER	INSIDE DIAMETER	ONE WIRE IN TUBE
$1\frac{1}{8}$ inch	$\frac{1}{2}$ inch	No. 12
$1\frac{1}{4}$ "	$\frac{3}{8}$ "	" 8
$1\frac{1}{2}$ "	$\frac{1}{2}$ "	" 6
$1\frac{3}{4}$ "	$\frac{5}{8}$ "	" 1
$1\frac{7}{8}$ "	$\frac{3}{4}$ "	" 2/0
2 "	1 "	250,000 C. M.
$2\frac{1}{8}$ "	$1\frac{1}{4}$ "	400,000 C. M.
$2\frac{1}{4}$ "	$1\frac{1}{2}$ "	750,000 C. M.
$2\frac{3}{8}$ "	$1\frac{3}{4}$ "	1,000,000 C. M.
$2\frac{1}{2}$ "	2 "	1,500,000 C. M.
$2\frac{7}{8}$ "	$2\frac{1}{4}$ "	2,000,000 C. M.

WIRES RUN EXPOSED ON INSULATORS

This method of wiring has the advantages of cheapness, durability, and accessibility.

Cheapness. The relative cost of this method of wiring as compared with that of the concealed conduit system, is about fifty per cent of the latter if rubber-covered conductors are used, and about forty per cent of the latter if weatherproof slow-burning conductors are used. As the *Rules* of the Fire Underwriters allow the use of weatherproof slow-burning conductors in dry places, considerable saving may be effected by this method of wiring, provided there is no objection to it



Fig. 18. Large Feeders Run Exposed on Insulators.

from the standpoint of appearance, and also provided that it is not liable to mechanical injury or disarrangement.

Durability. It is a well-known fact that rubber insulation has a relatively short life. Inasmuch as in this method of wiring, the insulation does not depend upon the insulation of the conductors, but on the insulators themselves, which are of glass or porcelain, this system is much more desirable than any of the other methods. Of course, if the conductors are mechanically injured, or the insulators broken, the insulation of the system is reduced; but there is no gradual deterioration as there is in the case of other methods of wiring, where

rubber is depended upon for insulation. This is especially true in hot places, particularly where the temperature is 120° F. or above. For such cases, the weatherproof slow-burning conductors on porcelain or glass insulators are especially recommended.

Accessibility. The conductors being run exposed, they may be readily repaired or removed, or connections may be made to the same.

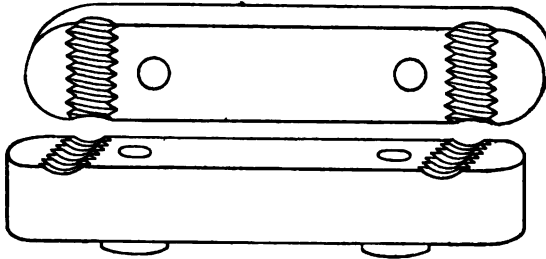


Fig. 19. Two-Wire Cleat.

This method of wiring is especially recommended for mills, factories, and for large or long feeder conductors. Fig. 18 shows examples of exposed large feeder con-

ductors, installed in the New York Life Insurance Building, New York City. For small conductors, up to say No. 6 B. & S. Gauge each, porcelain cleats may be used to support one, two, or three conductors, provided the distance between the conduc-

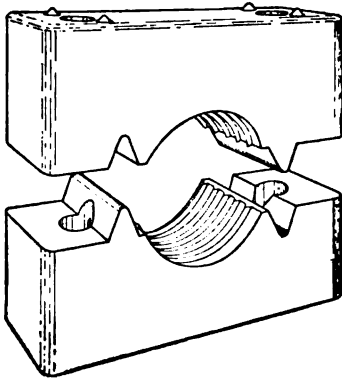


Fig. 20. One-Wire Cleat.

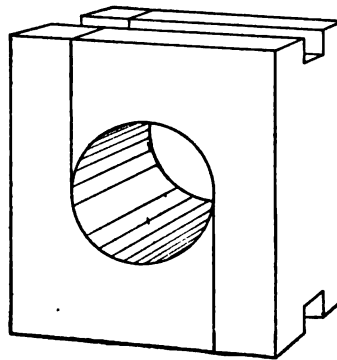


Fig. 21. Porcelain Insulator for Large Conductors.

tors is at least $2\frac{1}{2}$ inches in a two-wire system, and $2\frac{1}{2}$ inches between the two outside conductors in a three-wire system where the potential between the outside conductors is not over 300 volts. The cleat must hold the wire at least one-half inch from the surface to which the cleat is fastened; and in damp places the wire must be held at least one inch from the surface wired over. For larger conductors,

from No. 6 to No. 4 / 0 B. & S. Gauge, it is usual to use single porcelain cleats or knobs. Figs. 19 and 20 show a good form of two-wire

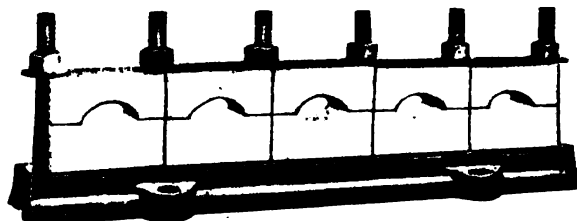


Fig. 22. Iron Rack and Insulators for Large Conductors.
Courtesy of General Electric Co., Schenectady, N. Y.

cleat and single-wire cleat, respectively.

For large feeder or main conductors from No. 4 / 0 B. & S. Gauge upward, a more substantial form of porcelain insulator should be used, such as shown in Fig. 21. These insulators are held in iron racks or angle-iron frames, of which two forms are shown in Figs. 22 and 23. The latter form of rack is particularly desirable for heavy conductors and where a number of conductors are run together. In this form of rack, any length of conductor can be removed without disturbing the other conductors.

As a rule, the porcelain insulators should be placed not more than $4\frac{1}{2}$ feet apart; and if the wires are liable to be disturbed, the distance between supports should be shortened, particularly for small conductors. If the beams are so far apart that supports cannot be obtained every $4\frac{1}{2}$ feet, it is necessary to provide a running board as shown in Fig. 24, to which the porcelain cleats and knobs can be fastened. Figs. 25 and 26 show two methods of supporting small conductors. For conductors of No. 8 B. & S.

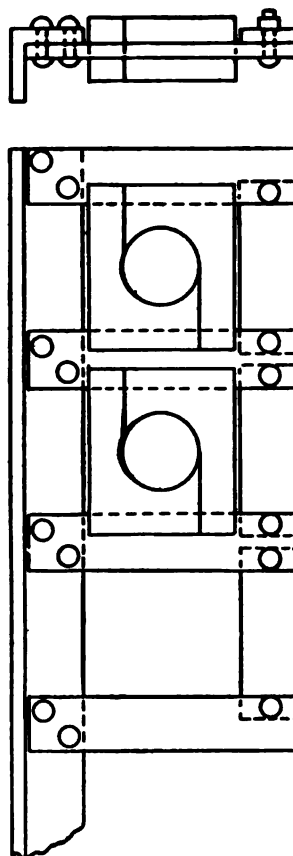


Fig. 23. Elevation and Plan of Insulators Held in Angle-Iron Frames.

Gauge, or over, it is not necessary to break around the beams, provided they are not liable to be disturbed; but the supports may be placed on each beam.

Where the distance between the supports, however, is greater than $4\frac{1}{2}$ feet, it is usually necessary to provide intermediate supports, as shown in

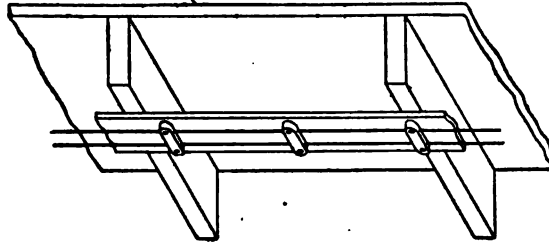


Fig. 24. Insulators Mounted on Running-Board across Wide-Spaced Beams.

Fig. 27, or else to provide a running-board. Another method which may be used, where beams are further than $4\frac{1}{2}$ feet apart, is to

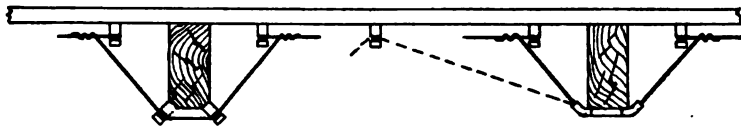


Fig. 25. Method of Supporting Small Conductors.

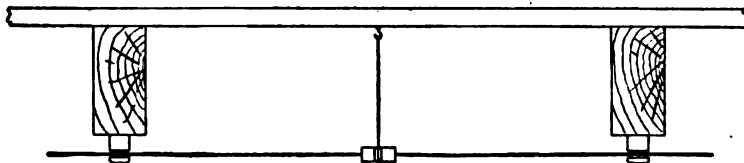


Fig. 27. Intermediate Support for Conductor between Wide-Spaced Beams.

run a main along the wall at right angles to the beams, and to have the individual circuits run between and parallel to the beams.

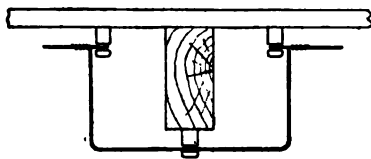


Fig. 26. Method of Supporting a Small Conductor.

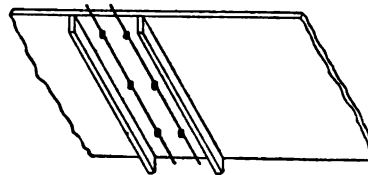


Fig. 28. Conductors Protected by Wooden Guard-Strips on Low Ceiling.

In low-ceiling rooms, where the conductors are liable to injury, it is usually required that a wooden guard strip be placed on each side of the conductors, as shown in Fig. 28.

Where the conductors pass through partitions or walls, they must

be protected by porcelain tubes, or, if the conductors be of rubber, by means of fibrous tubing placed inside of iron conduits.

All conductors on the walls for a height of not less than six feet from the ground, either should be boxed in, or, if they be rubber-covered, should (preferably) be run in iron conduits; and in conductors having single braid only, additional protection should be provided by means of flexible tubing placed inside of the iron conduit.

Where conductors cross each other, or where they cross iron pipes, they should be protected by means of porcelain tubes fastened with tape or in some other substantial manner that will prevent the tubes from slipping out of place.

TWO-WIRE AND THREE-WIRE SYSTEMS

As both the two-wire and the three-wire system are extensively used in electric wiring, it will be well to give some consideration to the advantages and disadvantages of each system, and to explain them somewhat in detail.

Relative Advantages. The choice of either a two-wire or a three-wire system depends largely upon the source of supply. If, for example, the source of supply will always probably be a 120-volt, two-wire system, there would be no object in installing a three-wire system for the wiring. If, on the other hand, the source of supply is a 120-240-volt system, the wiring should, of course, be made three-wire. Furthermore, if at the outset the supply were two-wire, but with a possibility of a three-wire system being provided later, it would be well to adapt the electric wiring for the three-wire system, making the neutral conductor twice as large as either of the outside conductors, and combining the two outside conductors to make a single conductor until such time as the three-wire service is installed. Of course, there would be no saving of copper in this last-mentioned three-wire system, and in fact it would be slightly more expensive than a two-wire system, as will be shortly explained.

The object of the three-wire system is to reduce the amount of copper—and consequently the cost of wiring—necessary to transmit a given amount of electric power. As a rule, the proposition is usually one of lighting and not of power, for the reason that by means of the three-wire system we are able to increase the potential at which the current is transmitted, and at the same time to take advantage of the

greater efficiency of the lower voltage lamp. If current for power (motors, etc.) only were to be transmitted, it would be a simple matter to wind the motors, etc., for a higher voltage, and thereby reduce the weight of copper.

If, however, we increase the voltage of lamps, we find that they are not so efficient, nor is their life so long. With the standard carbon

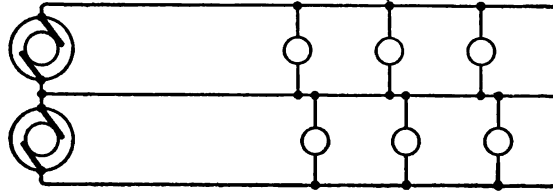


Fig. 29. Three-Wire System, with Neutral Conductor between the Two Outside Conductors.

lamp, it has been found that the 240-volt lamp, with the same life, requires about 10 to 12 per cent more current than the corresponding 120-volt lamp. Furthermore, in the case of the more efficient lamps recently introduced (such as the Tantalum lamp, Tungsten lamp, etc.), it has been found impracticable, if not impossible, to make them for pressures above 125 volts. For this reason the three-wire system is employed, for by this method we can use 240 volts across the outside conductors, and by the use of a neutral conductor obtain 120 volts between the neutral and the outside conductor, and thereby be enabled to use 120-volt lamps. Furthermore, if a 240-volt lamp should ever be placed on the market that was as economical as the lower voltage lamp, the result would be that the 240-480-volt system would be introduced, and 240-volt lamps used. As a

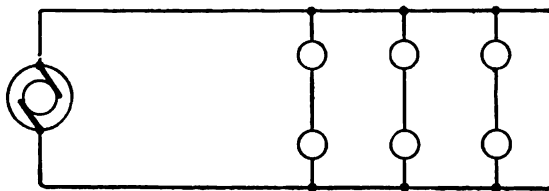


Fig. 30. Lamps Arranged in Pairs in Series, Dispensing with Necessity for Third or Neutral Conductor.

matter of fact, this has been tried in several cities—and particularly in Providence, Rhode Island. As a rule, however, the 120-volt lamp has been

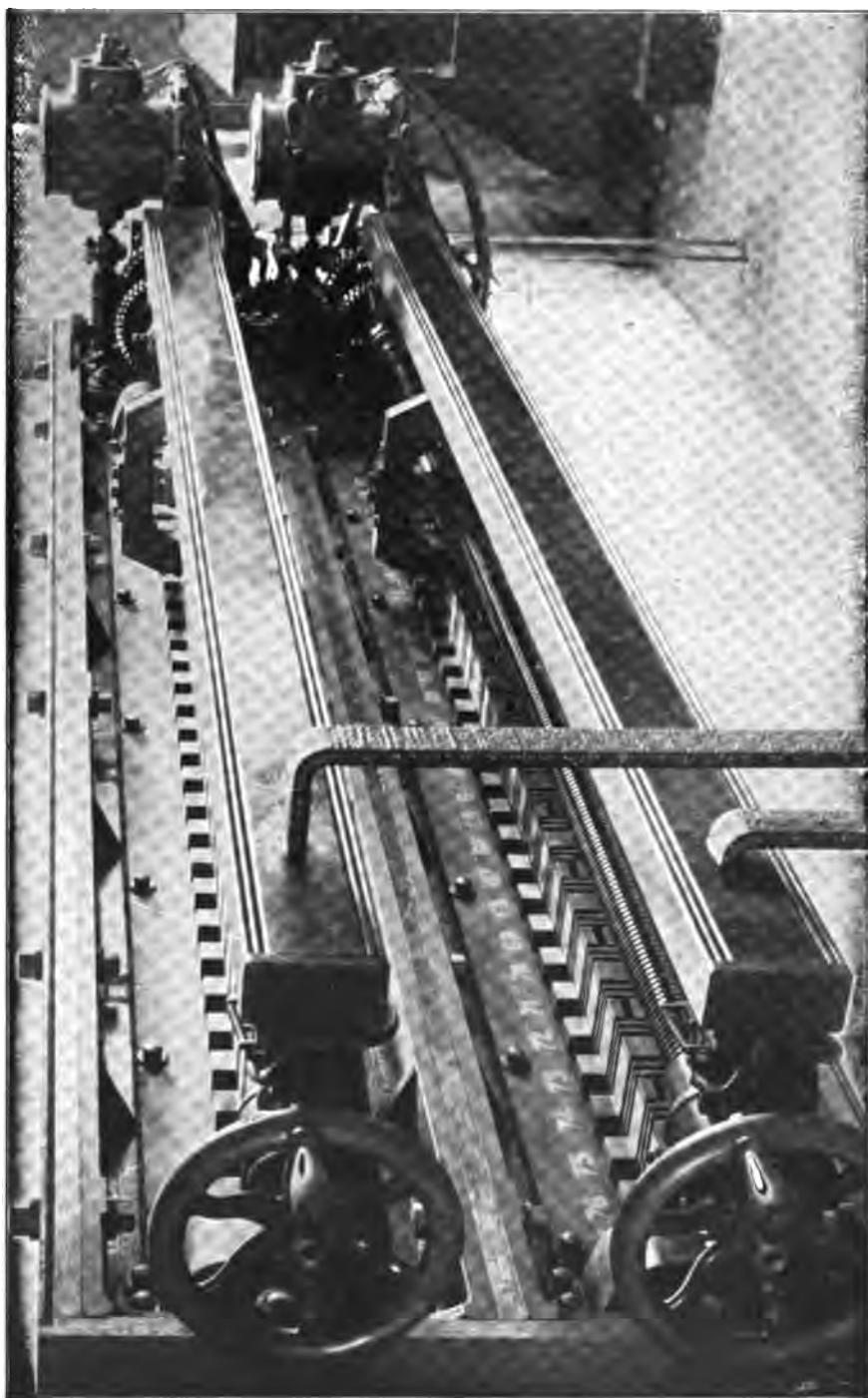
found so much more satisfactory as regards life, efficiency, etc., that it is nearly always employed.

The two-wire system is so extremely simple that no explanation whatever is required concerning it.

The three-wire system, however, is somewhat confusing, and will now be considered.

Details of Three-Wire System. The three-wire system may be considered as a two-wire system with a third or neutral conductor placed between the two outside conductors, as shown in Fig. 29. This neutral conductor would not be required if we could always have the lamps arranged in pairs, as shown in Fig. 30. In this case, the two lamps would burn in series, and we could transmit the current at double the usual voltage, and thereby supply twice the number of lamps with one-quarter the weight of copper, allowing the same loss in pressure in the lamps. The reason for this is, that, having the lamps arranged in series of pairs, we reduce the current to one-half, and, as the pressure at which the current is transmitted is doubled, we can again reduce the copper one-half without increasing the loss in lamps. We therefore see that we have a double saving, as the current is reduced one-half, which reduces the weight of copper one-half, and we can again reduce the copper one-half by doubling the loss in volts without increasing the percentage loss. For example, if in one case we had a straight two-wire system transmitting current to 100 lamps at a potential of 100 volts, and this system were replaced by one in which the lamps were placed in series of pairs, as shown in Fig. 30, and the potential increased to 200 volts—100 lamps still being used—we should find, in the latter case, that we were carrying current really for only 50 lamps, as we would require only the same amount of current for two lamps now that we required for one lamp before. Furthermore, as the potential would now be 200 instead of 100 volts, we could allow twice as much loss as in the first case, because the loss would now be figured as a percentage of 200 volts instead of a percentage of 100 volts. From this, it will readily be seen that in the second case mentioned, we would require only one-quarter the weight of copper that would be required in the first case.

It will readily be seen, however, that a system such as that outlined in the second scheme having two lamps, would be impracticable for ordinary purposes, for the reason that it would always require the lamps to be burned in pairs. Now, it is for this very reason that the third or neutral conductor is required; and, if this conductor be added, it will no longer be necessary to burn the lamps in pairs. This, then, is the object of the three-wire system—to enable us to reduce the amount of copper required for transmitting current, without increasing the electric pressure employed for the lamps.



End Cell Regulating Switches
Minneapolis General Electric Company

With regard to the size of the neutral conductor, one important point must be borne in mind; and that is, that the *Rules of the National Electric Code* require the neutral conductor in all interior wiring to be made at least as large as either of the two outside conductors. The reasons for this from a fire standpoint are obvious, because, if for any reason either of the outside conductors became disconnected, the neutral wire might be required to carry the same current as the outside conductors, and therefore it should be of the same capacity. Of course, the chances of such an event happening are slight; but, as the fire hazard is all-important, this rule must be complied with for interior wiring or in all cases where there would be a probability of fire. For outside or underground work, however, where the fire hazard would be relatively unimportant, the neutral conductor might be reduced in size; and, as a matter of fact, it is made smaller than the outside conductors.

The three-wire system is sometimes installed where it is desired to use the system as a two-wire, 125-volt system, or to have it arranged so that it may be used at any time also as a three-wire, 125-250-volt system. Of course, in order to do this, it is necessary to make the neutral conductor equal to the combined capacity of the outside conductors, the latter being then connected together to form one conductor, the neutral being the return conductor. This system is not recommended except in such instances, for example, as where an isolated plant of 125 volts is installed, and where there is a possibility of changing over at some future time to the three-wire, 125-250-volt system. In such a case as this, however, it would be better, where possible, to design the isolated plant for a three-wire, 125-250-volt system originally, and then to make the neutral conductor the same size as each of the two outside conductors.

The weight of copper required in a three-wire system where the neutral conductor is the same size as either of the two outside conductors, is $\frac{3}{4}$ of that required for a corresponding two-wire system using the same voltage of lamps.* It is obvious that this is true, because,

*NOTE.—If, in the two-wire system, we represent the weight of each of the two conductors by $\frac{1}{2}$, the weight of each of the outside conductors in a three-wire system would be represented by $\frac{1}{2}$; and if we had three conductors of the same size, we would have $\frac{1}{2} + \frac{1}{2} + \frac{1}{2} = \frac{3}{2}$ of the weight of copper required in a three-wire system, which would be required in a corresponding two-wire system having the same percentage of loss and using the same voltage of lamps.

If the neutral conductor were made $\frac{1}{2}$ of the size of each of the outside conductors, as is sometimes done in underground work, the total weight of copper required would be $\frac{1}{2} + \frac{1}{2} + \frac{1}{2} = \frac{3}{2}$ of that required in the corresponding two-wire system.

as the discussion proved concerning the arrangement shown in Fig. 30, where the lamps were placed in series of pairs, we found that the weight of copper for the two conductors was one-quarter the weight of the regular two-wire system. It is then of course true, that, if we had another conductor of the same size as each of the outside conductors, we increase the weight of copper one-half, or one-quarter plus one-half of one-quarter—that is, three-eighths.

In the three-wire system frequently used in isolated plants in which the two outside conductors are joined together and the neutral conductor made equal to their combined capacity, there is no saving of copper, for the reason that the same voltage of transmission is used, and, consequently, we have neither reduced the current nor increased the potential. Furthermore, though the weight of copper is the same, it is now divided into three conductors, instead of two, and naturally it costs relatively more to insulate and manufacture three conductors than to insulate and manufacture two conductors having the same total weight of copper. As a matter of fact, the three-wire system, having the neutral conductor equal to the combined capacity of the two outside ones, the latter being joined together, is about 8 to 10 per cent more expensive than the corresponding straight two-wire system.

In interior wiring, as a rule, where the three-wire system is used for the mains and feeders, the two-wire system is nearly always employed for the branch circuits. Of course, the two-wire branch circuits are then balanced on each side of the three-wire system, so as to obtain as far as possible at all times an equal balance on the two sides of the system. This is done so as to have the neutral conductor carry as little current as possible. From what has already been said, it is obvious that in case there is a perfect balance, the lamps are virtually in series of pairs, and the neutral conductor does not carry any current. Where there is an unbalanced condition, the neutral conductor carries the difference between the current on one side and the current on the other side of the system. For example, if we had five lamps on one side of the system and ten lamps on the other, the neutral conductor would carry the current corresponding to five lamps.

In calculating the three-wire system, the neutral conductor is disregarded, the outer wires being treated as a two-wire circuit, and the calculation is for one-half the total number of lamps, the per-

centage of loss being based on the potential across the two outside conductors.

The three-wire system is very generally employed in alternating-current secondary wiring, as nearly all transformers are built with three-wire connections.

While unbalancing will not affect the total loss in the outside conductors, yet it does affect the loss in the lamps, for the reason that the system is usually calculated on the basis of a perfect balance, and the loss is divided equally between the two lamps (the latter being considered in series of pairs). If, however, there is unbalancing to a great degree, the loss in lamps will be increased; and if the entire load is thrown over on one side, the loss in the lamps will be doubled on the remaining side, because the total loss in voltage will now occur in these lamps, whereas, in the case of perfect balance, it would be equally divided between the two groups of lamps.

CALCULATION OF SIZES OF CONDUCTORS

The formula for calculating the sizes of conductors for direct currents, where the length, load, and loss in volts are given, is as follows:

The size of conductor (in circular mils) is equal to the current *multiplied* by the distance (one way), *multiplied* by 21.6, *divided* by the loss in volts; or,

$$CM = \frac{C \times D \times 21.6}{V} \dots\dots\dots (1)$$

in which C = Current, in amperes;

D = Distance or length of the circuit (one way, in feet);

V = Loss in volts between the beginning and end of the circuit.

The constant (21.6) of this formula is derived from the resistance of a mil foot of wire of 98 per cent conductivity at 25° Centigrade or 77° Fahrenheit. The resistance of a conductor of one mil diameter and one foot long, is 10.8 at the temperature and conductivity named. We multiply this figure (10.8) by 2, as the length of a circuit is usually given as the distance one way, and in order to obtain the resistance of both conductors in a two-wire circuit, we must multiply by 2. The formula as above given, therefore, is for a two-wire circuit; and in calculating the size of conductors in a three-wire system, the calculation should be made on a two-wire basis, as explained hereinafter.

Formula 1 can be transformed so as to obtain the loss in a given circuit, or the current which may be carried a given distance with a stated loss, or to obtain the distance when the other factors are given, in the following manner:

Formula for Calculating Loss in Circuit when Size, Current, and Distance are Given

$$V = \frac{C \times D \times 21.6}{CM} \dots \dots \dots (2)$$

Formula for Calculating Current which may be Carried by a Given Circuit of Specified Length, and with a Specified Loss

$$C = \frac{CM \times V}{D \times 21.6} \dots \dots \dots (3)$$

Formula for Calculating Length of Circuit when Size, Loss, and Current to be Carried are Given

$$D = \frac{CM \times V}{C \times 21.6} \dots \dots \dots (4)$$

Formulae are frequently given for calculating sizes of conductors, etc., where the load, instead of being given in amperes, is stated in lamps or in horse-power. It is usually advisable, however, to reduce the load to amperes, as the efficiency of lamps and motors is a variable quantity, and the current varies correspondingly.

It is sometimes convenient, however, to make the calculation in terms of watts. It will readily be seen that we can obtain a formula expressed in watts from Formula 1. To do this, it is advisable to express the loss in volts in percentage, instead of actual volts lost. It must be remembered that, in the above formulæ, V represents the volts lost in the circuit, or, in other words, the difference in potential between the beginning and the end of the circuit, and is not the applied E. M. F. The loss in percentage, in any circuit, is equal to the actual loss expressed in volts, *divided by* the line voltage, *multiplied by* 100; or,

$$P = \frac{V}{E} \times 100.$$

From this equation, we have:

$$V = \frac{P E}{100}.$$

If, for example, the calculation is to be made on a loss of 5 per cent, with an applied voltage of 250, using this last equation, we would have:

$$V = \frac{5 \times 250}{100} = 12.5 \text{ volts.}$$

Substituting the equation $V = \frac{P E}{100}$ in Formula 1, we have:

$$\begin{aligned}
 C M &= \frac{C \times D \times 21.6}{\frac{P E}{100}} \\
 &= \frac{C \times D \times 21.6 \times 100}{P E} \\
 &= \frac{C \times D \times 2,160}{P E}
 \end{aligned}$$

This equation, it should be remembered, is expressed in terms of applied voltage. Now, since the power in watts is equal to the applied voltage *multiplied by* the current ($W = EC$), it follows that

$$C = \frac{W}{E}.$$

By substituting this value of C in the equation given above ($C M = \frac{C \times D \times 2,160}{P E}$), the formula is expressed in terms of watts instead of current, thus:

$$CM = \frac{W \times D \times 2,160}{E P E}, \dots\dots\dots(5)$$

in which W = Power in watts transmitted;

D = Length of the circuit (one way)—that is, the length of one conductor;

P = Figure representing the percentage loss;

E^* = Applied voltage.

All the above formulæ are for calculations of two-wire circuits. In making calculations for three-wire circuits, it is usual to make the calculation on the basis of the two outside conductors; and in three wire calculations, the above formulæ can be used with a slight modification, as will be shown.

In a three-wire circuit, it is usually assumed in making the calculation, that the load is equally balanced on the two sides of the neutral conductor; and, as the potential across the outside conductors is double that of the corresponding potential across a two-wire circuit, it is evident that for the same size of conductor the total loss in volts could be doubled without increasing the percentage of loss in lamps. Furthermore, as the load on one side of the neutral conductor, when the system is balanced, is virtually in series with the load on the third side, the current in amperes is usually one-half the sum of the current required by all the lamps. If C be still taken as the total

*NOTE. Remember that V in Formulæ 1 to 4 represents the volts lost, but that E in Formula 5 represents the applied voltage.

current in amperes (that is, the sum of the current required by all of the lamps) in Formula 1, we shall have to divide this current by 2, to use the formula for calculating the two outside conductors for a three-wire system. Furthermore, we shall have to multiply the voltage lost in the lamps by 2, to obtain the voltage lost in the two outside conductors, for the reason that the potential of the outside conductors is double the potential required by the lamps themselves. In other words, Formula 1 will become:

$$CM = \frac{C \times D \times 21.6}{2 \times V \times 2} \\ = \frac{C \times D \times 21.6}{4V}, \dots\dots\dots (6)$$

in which C = Sum of current required by all of the lamps on both sides of the neutral conductor;

D = Length of circuit—that is, of any one of the three conductors;

V = Loss allowed in the lamps, i. e., one-half the total loss in the two outside conductors.

In the same manner, all of the other formulæ may be adapted for making calculations for three-wire systems. Of course the calculation of a three-wire system could be made as if it were a two-wire system, by taking one-half the total number of lamps supplied, at one-half the voltage between the outside conductors.

It is understood, of course, that the size of the conductor in Formula 6 is the size of each of the two outside ones; but, inasmuch as the *Rules of the National Electric Code* require that for interior wiring the neutral conductor shall be at least equal in size to the outside conductors, it is not necessary to calculate the size of the neutral conductor. It must be remembered, however, that, in a three-wire system where the neutral conductor is made equal in capacity to the combined size of the two outside conductors, and where the two outside conductors are joined together, we have virtually a two-wire system arranged so that it can be converted into a three-wire system later. In this case the calculation is exactly the same as in the case of the two-wire circuits, except that one of the two conductors is split into two smaller wires of the same capacity. This is frequently done where isolated plants are installed, and where the generators are wound for 125 volts and it may be desired at times to take current from an outside three-wire 125-250-volt system.

METHOD OF PLANNING A WIRING INSTALLATION

The first step in planning a wiring installation, is to gather all the data which will affect either directly or indirectly the system of wiring and the manner in which the conductors are to be installed. These data will include: Kind of building; construction of building; space available for conductors; source and system of electric-current supply; and all details which will determine the method of wiring to be employed. These last items materially affect the cost of the work, and are usually determined by the character of the building and by commercial considerations.

Method of Wiring. In a modern fireproof building, the only system of wiring to be recommended is that in which the conductors are installed in rigid conduits; although, even in such cases, it may be desirable, and economy may be effected thereby, to install the larger feeder and main conductors exposed on insulators using weatherproof slow-burning wire. This latter method should be used, however, only where there is a convenient runway for the conductors, so that they will not be crowded and will not cross pipes, ducts, etc., and also will not have too many bends. Also, the local inspection authorities should be consulted before using this method.

For mills, factories, etc., wires exposed on cleats or insulators are usually to be recommended, although rigid conduit, flexible conduit, or armored cable may be desirable.

In finished buildings, and for extensions of existing outlets, where the wiring could not readily or conveniently be concealed, moulding is generally used, particularly where cleat wiring or other exposed methods of wiring would be objectionable. However, as has already been said, moulding should not be employed where there is any liability to dampness.

In finished buildings, particularly where they are of frame construction, flexible steel conduits or armored cable are to be recommended.

While in new buildings of frame construction, knob and tube wiring are frequently employed, this method should be used only where the question of first cost is of prime importance. While armored cable will cost approximately 50 to 100 per cent more than knob and

tube wiring, the former method is so much more permanent and is so much safer that it is strongly recommended.

Systems of Wiring. The system of wiring—that is, whether the two-wire or the three-wire system shall be used—is usually determined by the source of supply. If the source of supply is an isolated plant, with simple two-wire generators, and with little possibility of current being taken from the outside at some future time, the wiring in the building should be laid out on the two-wire system. If, on the other hand, the isolated plant is three-wire (having three-wire generators, or two-wire generators with balancer sets), or if the current is taken from an outside source, the wiring in the building should be laid out on a three-wire system.

It very seldom happens that current supply from a central station is arranged with other than the three-wire system inside of buildings, because, if the outside supply is alternating current, the transformers are usually adapted for a three-wire system. For small buildings, on the other hand, where there are only a few lights and where there would be only one feeder, the two-wire system is used. As a rule, however, when the current is taken from an outside source, it is best to consult the engineer of the central station supplying the current, and to conform with his wishes. As a matter of fact, this should be done in any event, in order to ascertain the proper voltage for the lamps and for the motors, and also to ascertain whether the central station will supply transformers, meters, and lamps—for, if these are not thus supplied, they should be included in the contract for the wiring.

Location of Outlets. It is not within the scope of this treatise to discuss the matter of *illumination*, but it is desirable, at this point, to outline briefly the method of procedure.

A set of plans, including elevation and details, if any, and showing decorative treatment of the various rooms, should be obtained from the Architect. A careful study should then be made by the Architect, the Owner, and the Engineer, or some other person qualified to make recommendations as to illumination. The location of the outlets will depend: *First*, upon the decorative treatment of the room, which determines the æsthetic and architectural effects; *second*, upon the type and general form of fixtures to be used, which should be previously decided on; *third*, upon the tastes of the owners or

occupants in regard to illumination in general, as it is found that tastes vary widely in regard to amount and kind of illumination.

The location of the outlets, and the number of lights required at each, having been determined, the outlets should be marked on the plans.

The Architect should then be consulted as to the location of the centers of distribution, the available points for the risers or feeders, and the available space for the branch circuit conductors.

In regard to the *rising points for the feeders and mains*, the following precautions should be used in selecting chases:

1. The space should be amply large to accommodate all the feeders and mains likely to rise at that given point. This seems trite and unnecessary, but it is the most usual trouble with chases for risers. Formerly architects and builders paid little attention to the requirements for chases for electrical work; but in these later days of 2-inch and 2½-inch conduit, they realize that these pipes are not so invisible and mysterious as the force they serve to distribute, particularly when twenty or more such conduits must be stowed away in a building where no special provision has been made for them.

2. If possible, the space should be devoted solely to electric wiring. Steam pipes are objectionable on account of their temperature; and these and all other pipes are objectionable in the same space occupied by the electrical conduits, for if the space proves too small, the electric conduits are the first to be crowded out.

The chase, if possible, should be continuous from the cellar to the roof, or as far as needed. This is necessary in order to avoid unnecessary bends or elbows, which are objectionable for many reasons.

In similar manner, the location of *cut-out cabinets or distributing centers* should fulfil the following requirements:

1. They should be accessible at all times.
2. They should be placed sufficiently close together to prevent the circuits from being too long.
3. Do not place them in too prominent a position, as that is objectionable from the Architect's point of view.
4. They should be placed as near as possible to the rising chases, in order to shorten the feeders and mains supplying them.

Having determined the system and method of wiring, the location of outlets and distributing centers, the next step is to lay out the *branch circuits* supplying the various outlets.

Before starting to lay out the branch circuits, a drawing showing the floor construction, and showing the space between the top of the beams and girders and the flooring, should be obtained from the Architect. In fireproof buildings of iron or steel construction, it is almost the invariable practice, where the work is to be concealed, to run the

conduits over the beams, under the rough flooring, carrying them between the sleepers when running parallel to the sleepers, and notching the latter when the conduits run across them (see Fig. 31). In wooden frame buildings, the conduits run parallel to the beams and to the furring (see Fig. 32); they are also sometimes run below the

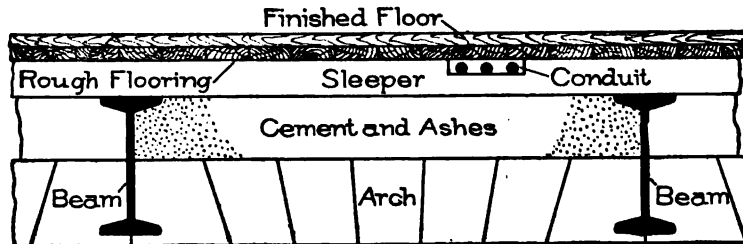


Fig. 31. Running Conductors Concealed under Floor in Fireproof Building.

beams. In the latter case the beams have to be notched, and this is allowable only in certain places, usually near the points where the beams are supported. The Architect's drawing is therefore necessary in order that the location and course of the conduits may be indicated on the plans.

The first consideration in laying out the branch circuit is the *number of outlets* and *number of lights* to be wired on any one branch circuit. The *Rules of the National Electric Code* (Rule 21-D) require that "no set of incandescent lamps requiring more than 660 watts, whether grouped on one fixture or on several fixtures or pendants, will be dependent on one cut-out." While it would be possible to have branch circuits supplying more than 660 watts, by placing various cut-outs at different points along the route of the branch circuit, so as to subdivide it into small sections to comply with the rule, this method is not recommended, except in certain cases, for exposed wiring in factories or mills. As a rule, the proper method is to have the cut-outs located at the center of distribution, and to limit each branch circuit to 660 watts, which corresponds to twelve or thirteen 50-watt lamps, twelve being the usual limit. Attention is called to the fact that the inspectors usually allow 50 watts for each socket connected to a branch circuit; and although 8-candle-power lamps may be placed at some of the outlets, the inspectors hold that the standard lamp is approximately 50 watts, and for that reason there is always the likelihood of a lamp of that capacity being used, and their inspec-

tion is based on that assumption. Therefore, to comply with the requirements, an allowance of not more than twelve lamps per branch circuit should be made.

In ordinary practice, however, it is best to reduce this number still further, so as to make allowance for future extensions or to increase the number of lamps that may be placed at any outlet. For this reason, it is wise to keep the number of the outlets on a circuit at the lowest point consistent with economical wiring. It has been proven by actual practice, that the best results are obtained by limiting the number to five or six outlets on a branch circuit. Of course, where all the outlets have a single light each, it is frequently necessary, for reasons of economy, to increase this number to eight, ten, and, in some cases, twelve outlets.

We have already referred to the location of the wires or conduits. This question is generally settled by the peculiarities of the construction of the building. It is necessary to know this, however, before laying out the circuit work, as it frequently determines the course of a circuit.

Now, as to the course of the circuit work, little need be said, as it is largely influenced by the relative position of the outlets, cut-

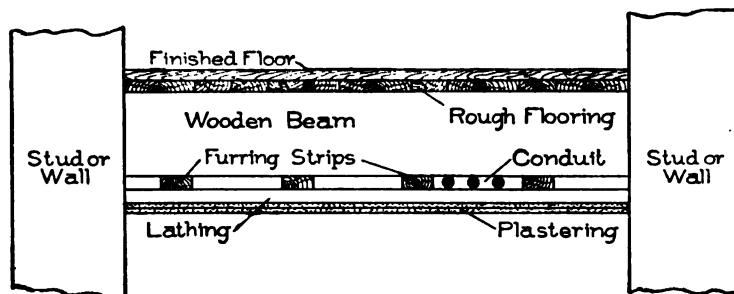


Fig. 32. Running Conductors Concealed under Floor in Wooden Frame Building.

outs, switches, etc. Between the cut-out box and the first outlet, and between the outlets, it will have to be decided, however, whether the circuits shall run at right angles to the walls of the building or room, or whether they shall run direct from one point to another, irrespective of the angle they make to the sleepers or beams. Of course, in the former case, the advantages are that the cost is somewhat less and the number of elbows and bends is reduced. If the

tubes are bent, however, instead of using elbows, the difference in cost is usually very slight, and probably does not compensate for the disadvantages that would result from running the tubes diagonally. As to the number of bends, if branch circuit work is properly laid out and installed, and a proper size of tube used, it rarely happens that there is any difference in "pulling" the branch circuit wires. It may happen, in the event of a very long run or one having a large number of bends, that it might be advisable to adopt a short and most direct route.

Up to this time, the location of the distribution centers has been made solely with reference to architectural considerations; but they must now be considered in conjunction with the branch circuit work.

It frequently happens that, after running the branch circuits on the plans, we find, in certain cases, that the position of centers of distribution may be changed to advantage, or sometimes certain groups may be dispensed with entirely and the circuits run to other points. We now see the wisdom of ascertaining from the Architect where cut-out groups may be located, rather than selecting particular points for their location.

As a rule, wherever possible, it is wise to limit the length of each branch circuit to 100 feet; and the number and location of the distributing centers should be determined accordingly.

It may be found that it is sometimes necessary and even desirable to increase the limit of length. One instance of this may be found in hall or corridor lights in large buildings. It is generally desirable, in such cases, to control the hall lights from one point; and, as the number of lights at each outlet is generally small, it would not be economical to run mains for sub-centers of distribution. Hence, in instances of this character, the length of runs will frequently exceed the limit named. In the great majority of cases, however, the best results are obtained by limiting the runs to 90 or 100 feet.

There are several good reasons for placing such a limit on the length of a branch circuit. To begin with, assuming that we are going to place a limit on the loss in voltage (drop) from the switchboard to the lamp, it may be easily proven that up to a certain reasonable limit it is more economical to have a larger number of distributing centers and shorter branch circuits, than to have fewer centers and longer circuits. It is usual, in the better class of work, to limit the

loss in voltage in any branch circuit to approximately one volt. Assuming this limit (one volt loss), it can readily be calculated that the number of lights at one outlet which may be connected on a branch circuit 100 feet long (using No. 14 B. & S. wire), is *four*; or in the case of outlets having a single light each, *five* outlets may be connected on the circuit, the first being 60 feet from the cut-out, the others being 10 feet apart.

These examples are selected simply to show that if the branch circuits are much longer than 100 feet, the loss must be increased to more than one volt, or else the number of lights that may be connected to one circuit must be reduced to a very small quantity, provided, of course, the size of the wire remains the same.

Either of these alternatives is objectionable—the first, on the score of regulation; and the second, from an economical standpoint. If, for instance, the loss in a branch circuit with all the lights turned on is four volts (assuming an extreme case), the voltage at which a lamp on that circuit burns will vary from four volts, depending on the number of lights burning at a time. This, of course, will cause the lamp to burn below candle-power when all the lamps are turned on, or else to diminish its life by burning above the proper voltage when it is the only lamp burning on the circuit. Then, too, if the drop in the branch circuits is increased, the sizes of the feeders and the mains must be correspondingly increased (if the total loss remains the same), thereby increasing their cost.

If the number of lights on the circuit is decreased, we do not use to good advantage the available carrying capacity of the wire.

Of course, one solution of the problem would be to increase the size of the wire for the branch circuits, thus reducing the drop. This, however, would not be desirable, except in certain cases where there were a few long circuits, such as for corridor lights or other special control circuits. In such instances as these, it would be better to increase the sizes of the branch circuit to No. 12 or even No. 10 B. & S. Gauge conductors, than to increase the number of centers of distribution for the sake of a few circuits only, in order to reduce the number of lamps (or loss) within the limit.

The method of calculating the loss in conductors has been given elsewhere; but it must be borne in mind, in calculating the loss of a branch circuit supplying more than one outlet, that separate calcu-

lations must be made for each portion of the circuit. That is, a calculation must be made for the loss to the first outlet, the length in this case being the distance from the center of distribution to the first outlet, and the load being the total number of lamps supplied by the circuit. The next step would be to obtain the loss between the first and second outlet, the length being the distance between the two outlets, and the load, in this case, being the total number of lamps supplied by the circuit, *minus* the number supplied by the first outlet; and so on. The loss for the total circuit would be the sum of these losses for the various portions of the circuit.

Feeders and Mains. If the building is more than one story, an elevation should be made showing the height and number of stories. On this elevation, the various distributing centers should be shown diagrammatically; and the current in amperes supplied through each center of distribution, should be indicated at each center. The next step is to lay out a tentative system of feeders and mains, and to ascertain the load in amperes supplied by each feeder and main. The estimated length of each feeder and main should then be determined, and calculation made for the loss from the switchboard to each center of distribution. It may be found that in some cases it will be necessary to change the arrangement of feeders or mains, or even the centers of distribution, in order to keep the total loss from the switchboard to the lamps within the limits previously determined. As a matter of fact, in important work, it is always best to lay out the entire work tentatively in a more or less crude fashion, according to the "cut and dried" method, in order to obtain the best results, because the entire layout may be modified after the first preliminary layout has been made. Of course, as one becomes more experienced and skilled in these matters, the final layout is often almost identical with the first preliminary arrangement.

TESTING

Where possible, two tests of the electric wiring equipment should be made, one after the wiring itself is entirely completed, and switches, cut-out panels, etc., are connected; and the second one after the fixtures have all been installed. The reason for this is that if a ground or short circuit is discovered before the fixtures are installed, it is more easily remedied; and secondly, because there is no division of

the responsibility, as there might be if the first test were made only after the fixtures were installed. If the test shows no grounds or short circuits before the fixtures are installed, and one does develop after they are installed, the trouble, of course, is that the short circuit or ground is one or more of the fixtures. As a matter of fact, it is a wise plan always to make a separate test of each fixture after it is delivered at the building and before it is installed.

While a *magneto* is largely used for the purpose of testing, it is at best a crude and unreliable method. In the first place, it does not give an indication, even approximately, of the total insulation resistance, but merely indicates whether there is a ground or short circuit, or not. In some instances, moreover, a magneto test has led to serious errors, for reasons that will be explained. If, as is nearly always the case, the magneto is an alternating-current instrument, it may sometimes happen—particularly in long cables, and especially where there is a lead sheathing on the cable—that the magneto will ring, indicating to the uninitiated that there is a ground or short circuit on the cable. This may be, and usually is, far from being the case; and the cause of the ringing of the magneto is not a ground or short circuit, but is due to the capacity of the cable, which acts as a condenser under certain conditions, since the magneto producing an alternating current repeatedly charges and discharges the cable in opposite directions, this changing of the current causing the magneto to ring. Of course, this defect in a magneto could be remedied by using a commutator and changing it to a direct-current machine; but as the method is faulty in itself, it is hardly worth while to do this.

A portable *galvanometer* with a resistance box and Wheatstone bridge, is sometimes employed; but this method is objectionable because it requires a special instrument which cannot be used for many other purposes. Furthermore, it requires more skill and time to use than the *voltmeter* method, which will now be described.

The advantage of the voltmeter method is that it requires merely a direct-current voltmeter, which can be used for many other purposes, and which all engineers or contractors should possess, together with a box of cells having a potential of preferably over 30 volts. The voltmeter should have a scale of not over 150 volts, for the reason that if the scale on which the battery is used covers too wide a range (say 1,000 volts) the readings might be so small as to make the test inac-

curate. A good arrangement would be to have a voltmeter having two scales—say, one of 60 and one of 600—which would make the voltmeter available for all practical potentials that are likely to be used inside of a building. If desired, a voltmeter could be obtained with three connections having three scales, the lowest scale of which would be used for testing insulation resistances.

Before starting a test, all of the fuses should be inserted and switches turned on, so that the complete test of the entire installation can be made. When this has been done, the voltmeter and battery should be connected, so as to obtain on the lowest scale of the voltmeter the electromotive force of the entire group of cells. This connection is shown in Fig. 33.

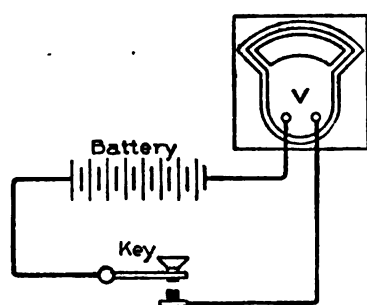
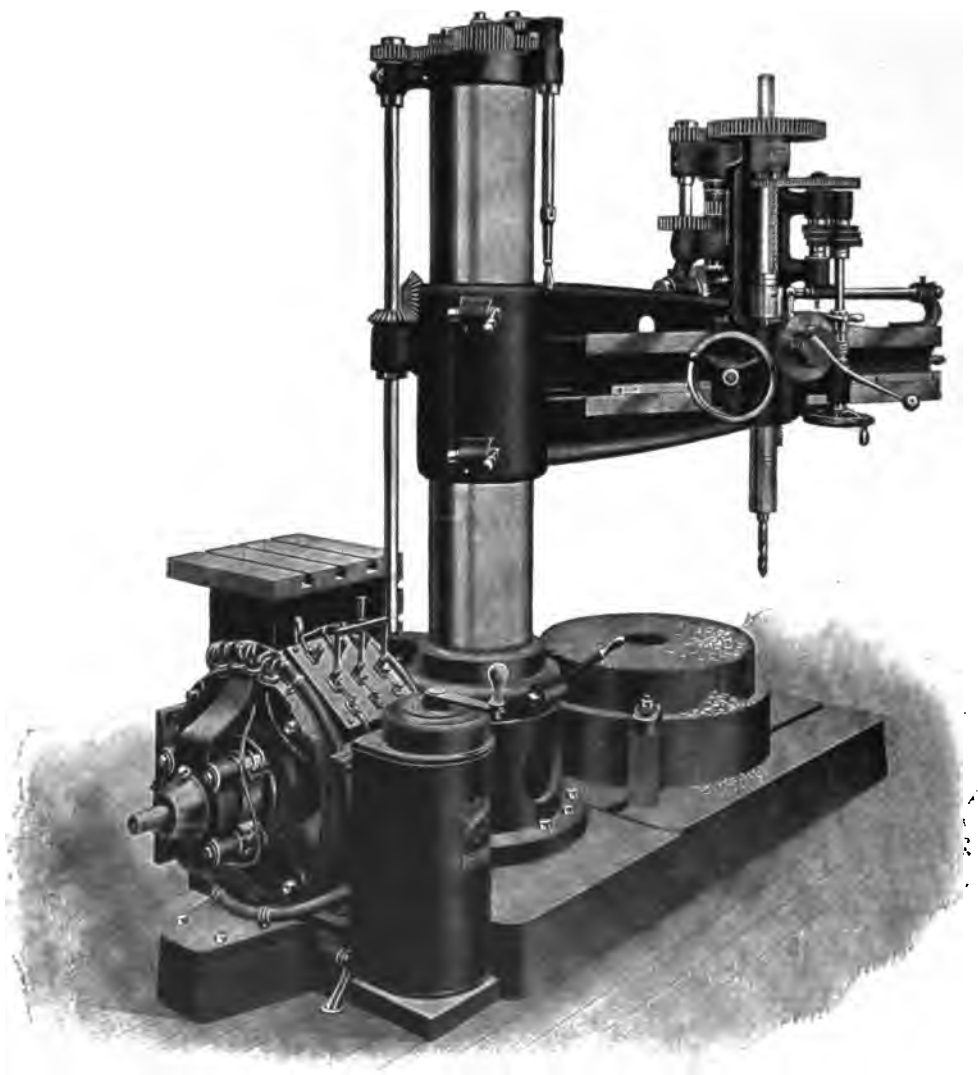


Fig. 33. Connections of Voltmeter and Battery for Testing Insulation Resistance.

Immediately after this has been done, the insulation resistance to be tested is placed in circuit, whether the insulation to be tested is a switch-board, slate panel-board, or the entire wiring installation; and the connections are made as shown in Fig. 34. A reading should then again be taken of the voltmeter; and the leakage is in proportion to the difference between the first and second readings of the voltmeter. The explanation given below

will show how this resistance may be calculated: It is evident that the resistance in the first case was merely the resistance of the voltmeter and the internal resistance of the battery. As a rule, the internal resistance of the battery is so small in comparison with the resistance of the voltmeter and the external resistance, that it may be entirely neglected, and this will be done in the following calculation. In the second case, however, the total resistance in circuits is the resistance of the voltmeter and the battery, *plus* the entire insulation resistance on all the wires, etc., connected in circuit.

To put this in mathematical form, the voltage of the cells may be indicated by the letter E ; and the reading of the voltmeter when the insulation resistance is connected by the circuit, by the letter E' . Let R represent the resistance of the voltmeter and R_x represent the insulation resistance of the installation which we wish to measure.



ALLIS-CHALMERS A. C. MOTOR DRIVING RADIAL DRILL

It is a fact which the reader undoubtedly knows, that the E. M. F. as indicated by the voltmeter in Fig. 34 is inversely proportional to the resistance: that is, the greater the resistance, the lower will be the reading on the voltmeter, as this reading indicates the leakage or current passing through the resistance. Putting this in the shape of a formula, we have from the theory of proportion:

$$E : E' :: R + R_x : R ;$$

or,

$$E' R + E' R_x = E R .$$

Transposing,

$$E' R_x = E R - E' R = R (E - E') ,$$

and

$$R_x = \frac{R (E - E')}{E'} .$$

Or, expressed in words, the insulation resistance is equal to the resistance of the voltmeter *multiplied by* the difference between the first reading (or the voltage in the cells) and the second reading (or the reading of the voltmeter with the insulation resistance in series with the voltmeter), *divided by* this last reading of the voltmeter.

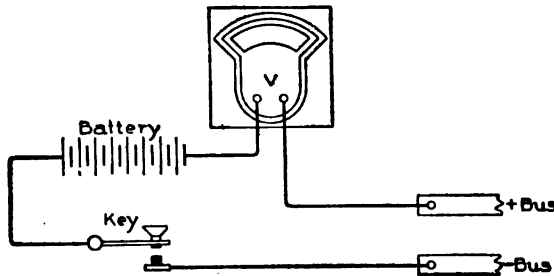


Fig. 34. Insulation Resistance Placed in Circuit, Ready for Testing.

Example. Assume a resistance of a voltmeter (R) of 20,000 ohms, and a voltage of the cells (E) of 30 volts; and suppose that the insulation resistance test of a wiring installation, including switchboard, feeders, branch circuits, panel-boards, etc., is to be made, the insulation resistance being represented by the letter R_x . By substituting in the formula

$$R_x = \frac{R (E - E')}{E'} ,$$

and assuming that the reading of the voltmeter with the insulation resistance connected is 5, we have:

$$R_x = \frac{20,000 \times (30 - 5)}{5} = 100,000 \text{ ohms.}$$

If the test shows an excessive amount of leakage, or a ground or

short circuit, the location of the trouble may be determined by the process of elimination—that is, by cutting out the various feeders until the ground or leakage disappears, and, when the feeder on which the trouble exists has been located, by following the same process with the branch circuits.

Of course, the larger the installation and the longer and more numerous the circuits, the greater the leakage will be; and the lower will be the insulation resistance, as there is a greater surface exposed for leakage. The *Rules of the National Electric Code* give a sliding scale for the requirements as to insulation resistance, depending upon the amount of current carried by the various feeders, branch circuits, etc. The rule of the *National Electric Code* (No. 66) covering this point, is as follows:

"The wiring in any building must test free from grounds; *i. e.*, the complete installation must have an insulation between conductors and between all conductors and the ground (not including attachments, sockets, receptacles, etc.) not less than that given in the following table:

Up to	5 amperes	4,000,000 ohms
"	10	2,000,000 "
"	25	800,000 "
"	50	400,000 "
"	100	200,000 "
"	200	100,000 "
"	400	50,000 "
"	800	25,000 "
"	1,600	12,500 "

"The test must be made with all cut-outs and safety devices in place. If the lamp sockets, receptacles, electroliers, etc., are also connected, only one-half of the resistances specified in the table will be required."

ALTERNATING-CURRENT CIRCUITS

It is not within the province of this chapter to treat the various alternating-current phenomena, but simply to outline the modifications which should be made in designing and calculating electric light wiring, in order to make proper allowance for these phenomena.

The most marked difference between alternating and direct current, so far as wiring is concerned, is the effect produced by self-induction, which is characteristic of all alternating-current circuits. This self-induction varies greatly with conditions depending upon the arrangement of the circuit, the medium surrounding the circuit, the devices or apparatus supplied by or connected in the circuit, etc.

For example, if a coil having a resistance of 100 ohms is included in the circuit, a current of one ampere can be passed through the coil with an electric pressure of 100 volts, if direct current is used; while it might require a potential of several hundred volts to pass a current of one ampere if alternating-current were used, depending upon the number of turns in the coil, whether it is wound on iron or some other non-magnetic material, etc.

It will be seen from this example, that greater allowance should be made for self-induction in laying out and calculating alternating-current wiring, if the conditions are such that the self-induction will be appreciable.

On account of self-induction, the two wires of an alternating-current circuit must never be installed in separate iron or steel conduits, for the reason that such a circuit would be virtually a *choke coil* consisting of a single turn of wire wound on an iron core, and the self-induction would not only reduce the current passing through the circuit, but also might produce heating of the iron pipe. It is for this reason that the *National Electric Code* requires conductors constituting a given circuit to be placed in the same conduit, if that conduit is iron or steel, whenever the said circuit is intended to carry, or is liable to carry at some future time, an alternating current. This does not mean, in the case of a two-phase circuit, that all four conductors need be placed in the same conduit, but that the two conductors of a given phase must be placed in the same conduit. If, however, the three-wire system be used for a two-phase system, all three conductors should be placed in the same conduit, as should also be the case in a three-wire three-phase system. Of course, in a single-phase two- or three-wire system, the conductors should all be placed in the same conduit.

In calculating circuits carrying alternating current, no allowance usually should be made for self-induction when the conductors of the same circuit are placed close together in an iron conduit. When, however, the conductors are run exposed, or are separated from each other, calculation should be made to determine if the effects of self-induction are great enough to cause an appreciable inductive drop. There are several methods of calculating this drop due to self-induction—one by formula, and one by a mathematical method which will be described.

Skin Effect. Skin effect in alternating-current circuits is caused by an incorrect distribution of the current in the wire, the current tending to flow through the outer portion of the wire, it being a well-known fact that in alternating currents, the current density decreases toward the center of the conductor, and that in large wires, the current density at the center of the conductor is relatively quite small.

The skin effect increases in proportion to the square of the diameter, and also in direct ratio to the frequency of the alternating current.

For conductors of No. 0000 B. & S. Gauge, and smaller, and for frequencies of 60 cycles per second, or less, the skin effect is negligible and is less than one-half of one per cent.

For very large cables and for frequencies above 60 cycles per second, the skin effect may be appreciable; and in certain cases, allowance for it should be made in making the calculation. In ordinary practice, however, it may be neglected. Table IX, taken from *Alternating-Current Wiring and Distribution*, by W. R. Emmet, gives the data necessary for calculating the skin effect. The figures given in the first and third columns are obtained by multiplying the size of the conductor (in circular mils) by the frequency (number of cycles per second); and the figures in the second and fourth columns show the factor to be used in multiplying the ohmic resistance, in order to obtain the combined resistance and skin effect.

TABLE IX
Data for Calculating Skin Effect

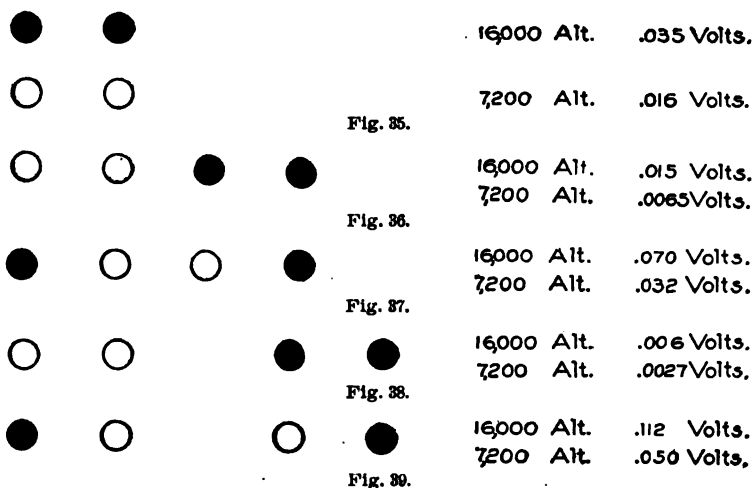
PRODUCT OF CIRCULAR MILS $\times$ CYCLES PER SEC.	FACTOR	PRODUCT OF CIRCULAR MILS $\times$ CYCLES PER SEC.	FACTOR
10,000,000	1.00	70,000,000	1.13
20,000,000	1.01	80,000,000	1.17
30,000,000	1.03	90,000,000	1.20
40,000,000	1.05	100,000,000	1.25
50,000,000	1.08	125,000,000	1.34
60,000,000	1.10	150,000,000	1.43

The factors given in this table, *multiplied by* the resistance to direct currents, will give the resistance to alternating currents for copper conductors of circular cross-section.

Mutual Induction. When two or more circuits are run in the same vicinity, there is a possibility of one circuit inducing an electromotive force in the conductors of an adjoining circuit. This effect may result in raising or lowering the E. M. F. in the circuit in which a

mutual induction takes place. The amount of this induced E. M. F. set up in one circuit by a parallel current, is dependent upon the current, the frequency, the lengths of the circuits running parallel to each other, and the relative positions of the conductors constituting the said circuits.

Under ordinary conditions, and except for long circuits carrying high potentials, the effect of mutual induction is so slight as to be negligible, unless the conductors are improperly arranged. In order to prevent mutual induction, the conductors constituting a given circuit should be grouped together. Figs. 35 to 39, inclusive, show



Various Groupings of Conductors in Two Two-Wire Circuits, Giving Various Effects of Induction.

five arrangements of two two-wire circuits; and show how relatively small the effect of first induction is when the conductors are properly arranged, as in Fig. 38, and how relatively large it may be when improperly arranged, as in Fig. 39. These diagrams are taken from a publication of Mr. Charles F. Scott, entitled *Polyphase Transmission*, issued by the Westinghouse Electric & Manufacturing Company.

Line Capacity. The effect of capacity is usually negligible, except in long transmission lines where high potentials are used; no calculations or allowance need be made for capacity, for ordinary circuits.

Calculation of Alternating-Current Circuits. In the instruction paper on "Power Stations and Transmission," a method is given for calculating alternating-current lines by means of formulæ, and data are given regarding power factor and the calculation of both single-phase and polyphase circuits. For short lines, secondary wiring, etc., however, it is probably more convenient to use the chart method devised by Mr. Ralph D. Mershon, described in the *American Electrician* of June, 1897, and partially reproduced as follows:

DROP IN ALTERNATING-CURRENT LINES

When alternating currents first came into use, when transmission distances were short and the only loads carried were lamps, the question of *drop* or *loss of voltage* in the transmitting line was a simple one, and the same methods as for direct current could without serious error be employed in dealing with it. The conditions existing in alternating practice to-day—longer distances, polyphase circuits, and loads made up partly or wholly of induction motors—render this question less simple; and direct-current methods applied to it do not lead to satisfactory results. Any treatment of this or of any engineering subject, if it is to benefit the majority of engineers, must not involve groping through long equations or complex diagrams in search of practical results. The results, if any, must be in available and convenient form. In what follows, the endeavor has been made to so treat the subject of drop in alternating-current lines that if the reader be grounded in the theory the brief space devoted to it will suffice; but if he do not comprehend or care to follow the simple theory involved, he may nevertheless turn the results to his practical advantage.

Calculation of Drop. Most of the matter heretofore published on the subject of drop treats only of the inter-relation of the E. M. F.'s involved, and, so far as the writer knows, there have not appeared in convenient form the data necessary for accurately calculating this quantity. Table X (page 47) and the chart (page 46) include, in a form suitable for the engineer's pocketbook, everything necessary for calculating the drop of alternating-current lines.

The chart is simply an extension of the vector diagram (Fig. 40), giving the relations of the E. M. F.'s of line, load and generator. In

Fig. 40, E is the generator E. M. F.; a the E. M. F. impressed upon the load; c , that component of E which overcomes the back E. M. F. due to the impedance of the line. The component c is made up of two components at right angles to each other. One is a , the component overcoming the IR or back E. M. F. due to resistance of the line. The other is b , the component overcoming the reactance E. M. F. or back E. M. F. due to the alternating field set up around the wire by the current in the wire. The drop is the difference between E and e . It is d , the radial distance between two circular arcs, one of which is drawn with a radius e , and the other with a radius E .

The chart is made by striking a succession of circular arcs with O as a center.

The radius of the smallest circle corresponds to e , the E. M. F. of the load, which is taken as 100 per cent. The radii of the succeeding circles increase by 1 per cent of that of the smallest circle; and, as the radius of the last or largest circle is 140 per cent

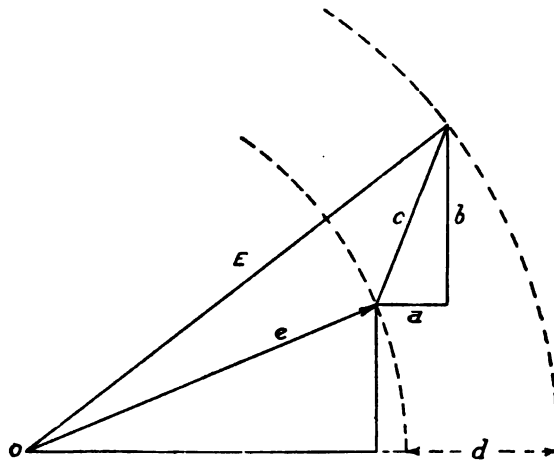


Fig. 40. Vector Diagram.

of that of the smallest, the chart answers for drops up to 40 per cent of the E. M. F. delivered.

The terms *resistance volts*, *resistance E. M. F.*, *reactance volts*, and *reactance E. M. F.*, refer, of course, to the voltages for overcoming the back E. M. F.'s due to resistance and reactance respectively. The figures given in the table under the heading "Resistance-Volts for One Ampere, etc." are simply the resistances of 2,000 feet of the various sizes of wire. The values given under the heading "Reactance-Volts, etc.," are, a part of them, calculated from tables published some time ago by Messrs. Houston and Kennelly. The remainder were obtained by using Maxwell's formula.

The explanation given in the table accompanying the chart

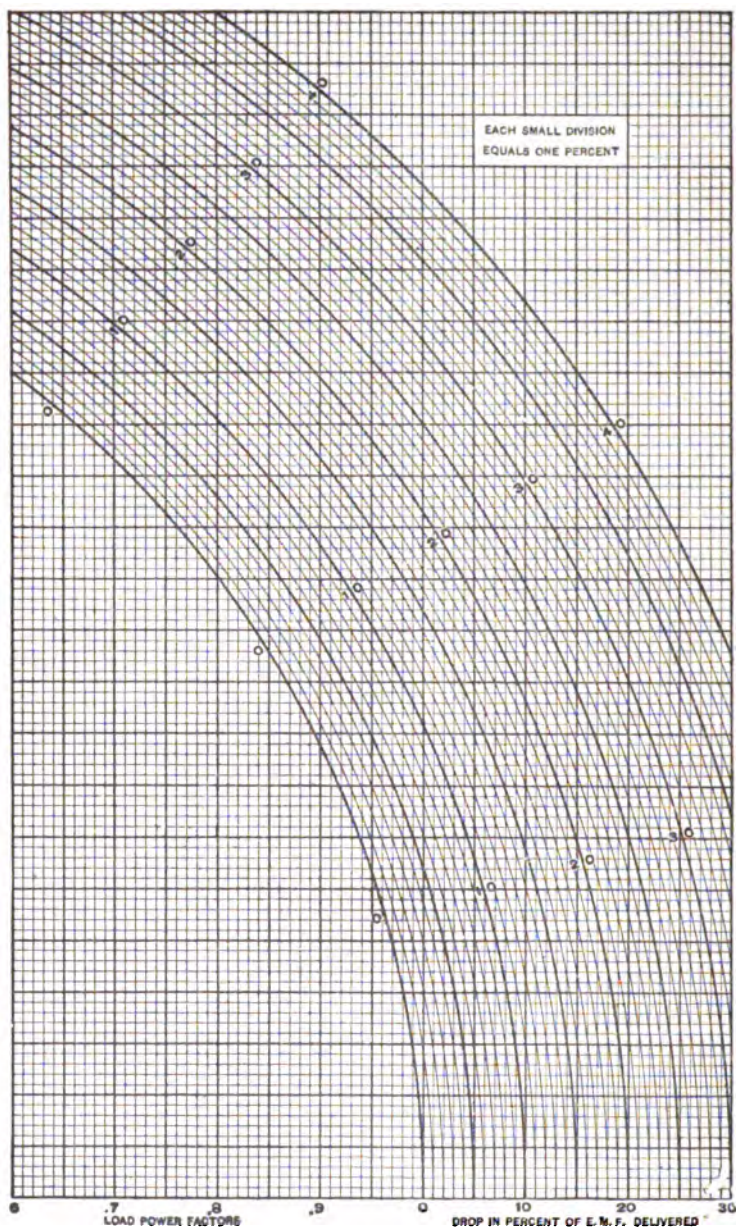


Chart for Calculating Drop in Alternating-Current Lines.

TABLE X
Data for Calculating Drop in Alternating-Current Lines

To be used in conjunction with Chart on opposite page.

By means of the table, calculate the *Resistance-Volts* and the *Reactance-Volts* in the line, and find what per cent each is of the E. M. F. delivered at the end of the line. Starting from the point on the chart where the vertical line corresponding with the power-factor of the load intersects the smallest circle, lay off in per cent the resistance E. M. F. horizontally and to the right; from the point thus obtained, lay off upward in per cent the reactance-E. M. F. The circle on which the last point falls gives the drop, in per cent, of the E. M. F. delivered at the end of the line. Every tenth circle arc is marked with the per cent drop to which it corresponds.

Size of wire—B. & S.	Upper figures are Weight in Lbs. per 1,000 ft. Single Wire	Upper figures are Resistance-Volts in 1,000 ft. of Line (2,000 ft. of wire) for One Ampere	Throughout the table the lower figures in the squares give values for ONE MILE of line, corresponding to those of the upper figures for 1,000 feet of line. Upper figures are REACTANCE-VOLTS in 1,000 ft. of Line (= 2,000 ft. of Wire) for One Ampere at 7,200 Alternations per Minute (60 Cycles per Second) for the distance given between Centers of Conductors.										
			½"	1"	2"	3"	6"	9"	12"	18"	24"	30"	36"
0000	639 3,376	.098 .518	.046 .243	.079 .417	.111 .586	.130 .687	.161 .850	.180 .951	.193 1.02	.212 1.13	.225 1.19	.235 1.24	.244 1.29
000	507 2,677	.124 .653	.052 .275	.085 .449	.116 .613	.135 .713	.167 .882	.185 .977	.199 1.06	.217 1.15	.230 1.22	.241 1.27	.249 1.32
00	402 2,123	.156 .824	.057 .301	.090 .475	.121 .689	.140 .739	.172 .908	.190 1.00	.204 1.08	.222 1.17	.236 1.25	.246 1.30	.254 1.34
0	319 1,685	.197 1.04	.063 .332	.095 .502	.127 .671	.145 .766	.177 .935	.196 1.04	.209 1.10	.228 1.20	.241 1.27	.251 1.33	.259 1.37
1	253 1,335	.248 1.31	.068 .359	.101 .533	.132 .687	.151 .797	.183 .966	.201 1.06	.214 1.13	.233 1.23	.246 1.30	.256 1.35	.265 1.40
2	201 1,059	.313 1.65	.074 .391	.106 .560	.138 .728	.156 .824	.188 .993	.206 1.09	.220 1.16	.238 1.26	.252 1.33	.262 1.38	.270 1.43
3	159 840	.394 2.08	.079 .417	.112 .591	.143 .755	.162 .856	.193 1.02	.212 1.12	.225 1.19	.244 1.29	.257 1.36	.267 1.41	.275 1.45
4	126 666	.497 2.63	.085 .449	.117 .618	.149 .787	.167 .882	.199 1.05	.217 1.15	.230 1.22	.249 1.32	.262 1.38	.272 1.44	.281 1.48
5	100 528	.627 3.31	.090 .475	.121 .639	.154 .813	.172 .908	.204 1.08	.223 1.18	.236 1.25	.254 1.34	.268 1.42	.278 1.47	.286 1.51
6	79 419	.791 4.18	.095 .502	.127 .671	.158 .834	.178 .940	.209 1.10	.228 1.20	.241 1.27	.260 1.37	.272 1.44	.283 1.49	.291 1.54
7	63 332	.997 5.27	.101 .533	.132 .697	.164 .866	.183 .966	.214 1.13	.233 1.23	.246 1.30	.265 1.40	.278 1.47	.288 1.52	.296 1.56
8	50 263	1.260 6.64	.106 .560	.138 .729	.169 .893	.188 .993	.220 1.16	.238 1.26	.252 1.33	.270 1.43	.284 1.50	.293 1.55	.302 1.60

(Table X) is thought to be a sufficient guide to its use, but a few examples may be of value.

Problem. Power to be delivered, 250 K.W.; E. M. F. to be delivered, 2,000 volts; distance of transmission, 10,000 feet; size of wire, No. 0; distance between wires, 18 inches; power factor of load, .8; frequency, 7,200 alternations per minute. Find the line loss and drop.

Remembering that the power factor is that fraction by which the apparent power of volt-amperes must be multiplied to give the true power, the apparent power to be delivered is

$$\frac{250 \text{ K.W.}}{.8} = 312.5 \text{ apparent K.W.}$$

The current, therefore, at 2,000 volts will be

$$\frac{312,500}{2,000} = 156.25 \text{ amperes.}$$

From the table of reactances under the heading "18 inches," and corresponding to No. 0 wire, is obtained the constant .228. Bearing the instructions of the table in mind, the reactance-volts of this line are, $156.25 \text{ (amperes)} \times 10 \text{ (thousands of feet)} \times .228 = 356.3 \text{ volts}$, which is 17.8 per cent of the 2,000 volts to be delivered.

From the column headed "Resistance-Volts" and corresponding to No. 0 wire, is obtained the constant .197. The resistance-volts of the line are, therefore, $156.25 \text{ (amperes)} \times 10 \text{ (thousands of feet)} \times .197 = 307.8 \text{ volts}$, which is 15.4 per cent of the 2,000 volts to be delivered.

Starting, in accordance with the instructions of the table, from the point where the vertical line (which at the bottom of the chart is marked "Load Power Factor" .8) intersects the inner or smallest circle, lay off horizontally and to the right the resistance-E. M. F. in per cent (15.4); and *from the point thus obtained*, lay off vertically the reactance-E. M. F. in per cent (17.8). The last point falls at about 23 per cent, as given by the circular arcs. This, then, is the drop, in per cent, of the E. M. F. delivered. The drop, in per cent, of the generator E. M. F. is, of course,

$$\frac{23}{100 + 23} = 18.7 \text{ per cent.}$$

The percentage *loss of power* in the line has not, as with direct current, the same value as the percentage drop. This is due to the fact that the line has reactance, and also that the apparent power

delivered to the load is not identical with the true power—that is, the load power factor is less than unity. The loss must be obtained by calculating $I^2 R$ for the line, or, what amounts to the same thing, by multiplying the resistance-volts by the current.

The resistance-volts in this case are 307.8, and the current 156.25 amperes. The loss is $307.8 \times 156.25 = 48.1$ K. W. The percentage *loss* is

$$\frac{48.1}{250 + 48.1} = 16.1 \text{ per cent.}$$

Therefore, for the problem taken, the *drop* is 18.7 per cent, and the *loss* is 16.1 per cent. If the problem be to find the size wire for a given drop, it must be solved by trial. Assume a size of wire and calculate the drop; the result in connection with the table will show the direction and extent of the change necessary in the size of wire to give the required drop.

The effect of the line reactance in increasing the drop should be noted. If there were no reactance, the drop in the above example would be given by the point obtained in laying off on the chart the resistance-E. M. F. (15.4) only. This point falls at 12.4 per cent, and the drop in terms of the generator E. M. F. would be

$$\frac{12.4}{112.4} = 11 \text{ per cent, instead of 18.7 per cent.}$$

Anything therefore which will reduce reactance is desirable.

Reactance can be reduced in two ways. One of these is to diminish the distance between wires. The extent to which this can be carried is limited, in the case of a pole line, to the least distance at which the wires are safe from swinging together in the middle of the span; in inside wiring, by the danger from fire. The other way of reducing reactance is to split the copper up into a greater number of circuits, and arrange these circuits so that there is no inductive interaction. For instance, suppose that in the example worked out above, two No. 3 wires were used instead of one No. 0 wire. The resistance-volts would be practically the same, but the reactance-volts would be less in the ratio $\frac{1}{2} \times \frac{.244}{.228} = .535$, since each circuit would bear half the current the No. 0 circuit does, and the constant for No. 3 wire is .244, instead of .228—that for No. 0. The effect of subdividing the copper is also shown if in the example given it is desired to reduce the drop

to, say, one-half. Increasing the copper from No. 0 to No. 0000 will not produce the required result, for, although the resistance-volts will be reduced one-half, the reactance-volts will be reduced only in the ratio $\frac{.212}{.228}$. If, however, *two* inductively independent circuits of No. 0

wire be used, the resistance- and reactance-volts will both be reduced one-half, and the drop will therefore be diminished the required amount.

The component of drop due to reactance is best diminished by subdividing the copper or by bringing the conductors closer together. It is little affected by change in size of conductors.

An idea of the manner in which changes of power factor affect drop is best gotten by an example. Assume distance of transmission, distance between conductors E. M. F., and frequency, the same as in the previous example. Assume the *apparent* power delivered the same as before, and let it be constant, but let the power factor be given several different values; the true power will therefore be a variable depending upon the value of the power factor. Let the size of wire be No. 0000. As the apparent power, and hence the current, is the same as before, and the line resistance is one-half, the resistance-E. M. F. will in this case be

$$\frac{15.4}{2}, \text{ or } 7.7 \text{ per cent of the E. M. F. delivered.}$$

Also, the reactance-E. M. F. will be

$$\frac{.212 \times 17.8}{.228} = 16.5 \text{ per cent.}$$

Combining these on the chart for a power factor of .4, and deducing the drop, in per cent, of the generator E. M. F., the value obtained is 15.3 per cent; with a power factor of .8, the drop is 14 per cent; with a power factor of unity, it is 8 per cent. If in this example the *true* power, instead of the *apparent* power, had been taken as constant, it is evident that the values of drop would have differed more widely, since the current, and hence the resistance- and reactance-volts, would have increased as the power factor diminished. The condition taken more nearly represents that of practice.

If the line had resistance and no reactance, the several values of drop, instead of 15.3, 14, and 8, would be 3.2, 5.7, and 7.2 per cent respectively, showing that for a load of lamps the drop will not

be much increased by reactance; but that with a load, such as induction motors, whose power factor is less than unity, care should be taken to keep the reactance as low as practicable. In all cases it is advisable to place conductors as close together as good practice will permit.

When there is a transformer in circuit, and it is desired to obtain the combined drop of transformer and line, it is necessary to know the resistance- and reactance-volts of the transformer. The resistance-volts of the combination of line and transformer are the sum of the resistance-volts of the line and the resistance-volts of the transformer. Similarly, the reactance-volts of the line and transformer are the sum of their respective reactance-volts. The resistance- and reactance-E. M. F.s of transformers may usually be obtained from the makers, and are ordinarily given in per cent.* These percentages express the values of the resistance- and reactance-E. M. F.'s when the transformer delivers its normal *full-load* current; and they express these values in terms of the normal *no-load* E. M. F. of the transformer.

Consider a transformer built for transformation between 1,000 and 100 volts. Suppose the resistance- and reactance-E. M. F.'s given are 2 per cent and 7 per cent respectively. Then the corresponding voltages when the transformer delivers full-load current, are 2 and 7 volts or 20 and 70 volts according as the line whose drop is required is connected to the low-voltage or high-voltage terminals. These values, 2—7 and 20—70, hold, no matter at what voltage the trans-

* When the required values cannot be obtained from the makers, they may be measured. Measure the resistance of both coils. If the line to be calculated is attached to the high-voltage terminals of the transformer, the equivalent resistance is that of the high-voltage coil, *plus* the resistance obtained by *increasing* in the square of the ratio of transformation the measured resistance of the low-voltage coil. That is, if the ratio of transformation is 10, the equivalent resistance referred to the high-voltage circuit is the resistance of the high-voltage coil, *plus* 100 times that of the low-voltage coil. This equivalent resistance multiplied by the high-voltage current gives the transformer resistance-volts referred to the high-voltage circuit. Similarly, the equivalent resistance referred to the low-voltage circuit is the resistance of the low-voltage coil, *plus* that of the high-voltage coil *reduced* in the square of the ratio of transformation. It follows, of course, from this, that the values of the resistance-volts referred to the two circuits bear to each other the ratio of transformation. To obtain the reactance-volts, short-circuit one coil of the transformer and measure the voltage necessary to force through the other coil its normal current at normal frequency. The result is, nearly enough, the reactance-volts. It makes no difference which coil is short-circuited, as the results obtained in one case will bear to those in the other the ratio of transformation. If a close value is desired, subtract from the square of the voltage reading the square of the resistance-volts, and take the square root of the difference as the reactance-volts.

former is operated, since they depend only upon the strength of current, providing it is of the normal frequency. If any other than the full-load current is drawn from the transformer, the reactance- and resistance-volts will be such a proportion of the values given above as the current flowing is of the full-load current. It may be noted, in passing, that when the resistance- and reactance-volts of a transformer are known, its regulation may be determined by making use of the chart in the same way as for a line having resistance and reactance.

As an illustration of the method of calculating the drop in a line and transformer, and also of the use of table and chart in calculating low-voltage mains, the following example is given:

Problem. A single-phase induction motor is to be supplied with 20 amperes at 200 volts; alternations, 7,200 per minute; power factor, .78. The distance from transformer to motor is 150 feet, and the line is No. 5 wire, 6 inches between centers of conductors. The transformer reduces in the ratio $\frac{2,000}{200}$, has a capacity of 25 amperes at 200 volts, and, when delivering this current and voltage, its resistance-E. M. F. is 2.5 per cent, its reactance-E. M. F. 5 per cent. Find the drop.

The reactance of 1,000 feet of circuit consisting of two No. 5 wires, 6 inches apart, is .204. The reactance-volts therefore are

$$.204 \times \frac{150}{1,000} \times 20 = .61 \text{ volts.}$$

The resistance-volts are

$$.627 \times \frac{150}{1,000} \times 20 = 1.88 \text{ volts.}$$

At 25 amperes, the resistance-volts of the transformer are 2.5 per cent of 200, or 5 volts. At 20 amperes, they are $\frac{20}{25}$ of this, or 4 volts.

Similarly, the transformer reactance-volts at 25 amperes are 10, and at 20 amperes are 8 volts. The combined reactance-volts of transformer and line are $8 + .61 = 8.61$, which is 4.3 per cent of the 200 volts to be delivered. The combined resistance-volts are $1.88 + 4$, or 5.88, which is 2.94 per cent of the E. M. F. to be delivered. Combining these quantities on the chart with a power factor of .78, the drop is 5 per cent of the delivered E. M. F.,

$$\text{or } \frac{5}{105} = 4.8 \text{ per cent}$$

of the impressed E. M. F. The transformer must be supplied with

$$\frac{2,000}{.952} = 2,100 \text{ volts,}$$

in order that 200 volts shall be delivered to the motor.

Table X (page 47) is made out for 7,200 alternations, but will answer for any other number if the values for reactance be changed in direct proportion to the change in alternations. For instance, for 16,000 alternations, multiply the reactances given by $\frac{16,000}{7,200}$.

For other distances between centers of conductors, interpolate the values given in the table. As the reactance values for different sizes of wire change by a constant amount, the table can, if desired, be readily extended for larger or smaller conductors.

The table is based on the assumption of sine currents and E. M. F.'s. The best practice of to-day produces machines which so closely approximate this condition that results obtained by the above methods are well within the limits of practical requirements.

Polyphase Circuits. So far, single-phase circuits only have been dealt with. A simple extension of the methods given above adapts them to the calculation of polyphase circuits. A four-wire *quarter-phase* (two-phase) transmission may, so far as loss and regulation are concerned, be replaced by two single-phase circuits identical (as to size of wire, distance between wires, current, and E. M. F.) with the two circuits of the quarter-phase transmission, provided that in both cases there is no inductive interaction between circuits. Therefore, to calculate a four-wire, quarter-phase transmission, compute the single-phase circuit required to transmit one-half the power at the same voltage. The quarter-phase transmission will require two such circuits.

A three-wire, *three-phase* transmission, of which the conductors are symmetrically related, may, so far as loss and regulation are concerned, be replaced by two single-phase circuits having no inductive interaction, and identical with the three-phase line as to size, wire, and distance between wires. Therefore, to calculate a three-phase transmission, calculate a single-phase circuit to carry one-half the load at the same voltage. The three-phase transmission will require three wires of the size and distance between centers as obtained for the single-phase.

A three-wire, quarter-phase transmission may be calculated

exactly as regards loss, and *approximately* as regards drop, in the same way as for three-phase. It is possible to exactly calculate the drop, but this involves a more complicated method than the approximate one. The error by this approximate method is generally small. It is possible, also, to get a somewhat less drop and loss with the same copper by proportioning the cross-section of the middle and outside wires of a three-wire, quarter-phase circuit to the currents they carry, instead of using three wires of the same size. The advantage, of course, is not great, and it will not be considered here.

WIRING AN OFFICE BUILDING

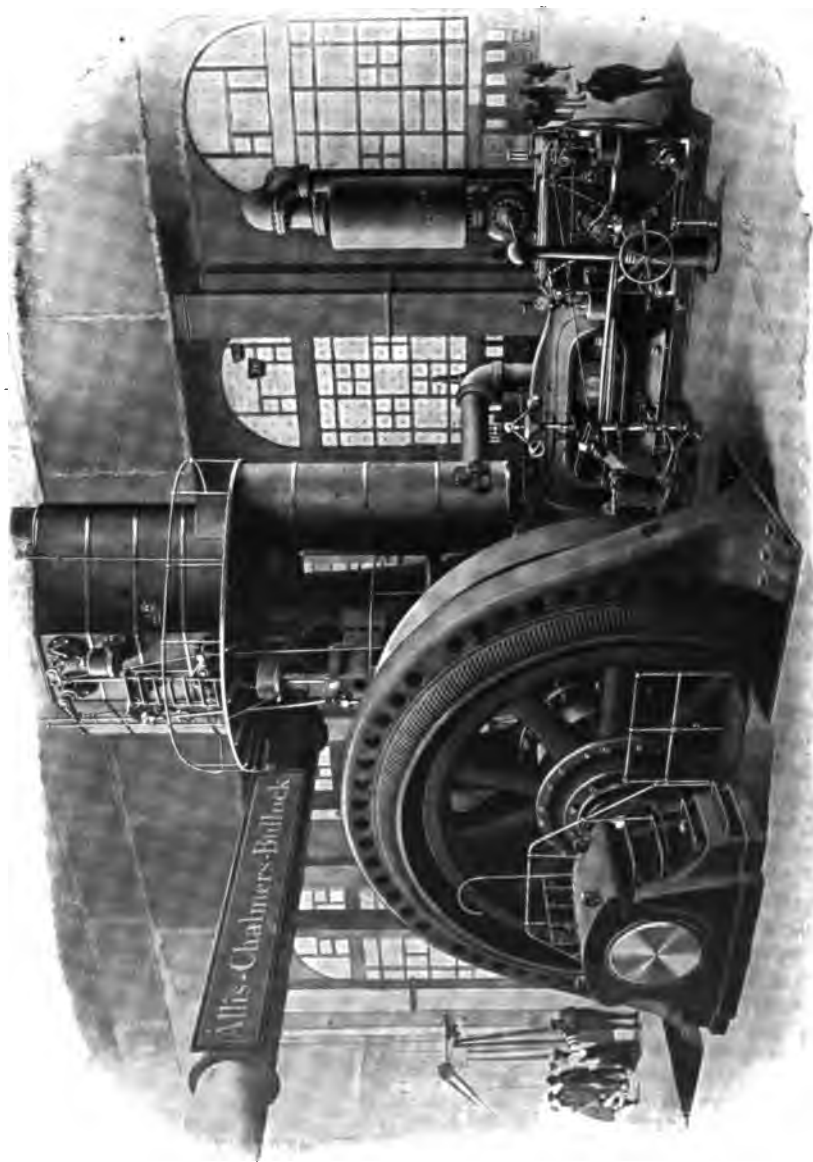
The building selected as a typical sample of a wiring installation is that of an office building located in Washington, D. C. The figures shown are reproductions of the plans actually used in installing the work.

The building consists of a basement and ten stories. It is of fireproof construction, having steel beams with terra-cotta flat arches. The main walls are of brick and the partition walls of terra-cotta blocks, finished with plaster. There is a space of approximately five inches between the top of the iron beams and the top of the finished floor, of which space about three inches was available for running the electric conduits. The flooring is of wood in the offices, but of concrete, mosaic, or tile in the basement, halls, toilet-rooms, etc.

The electric current supply is derived from the mains of the local illuminating company, the mains being brought into the front of the building and extending to a switchboard located near the center of the basement.

As the building is a very substantial fireproof structure, the only method of wiring considered was that in which the circuits would be installed in iron conduits.

Electric Current Supply. The electric current supply is direct current, two-wire for power, and three-wire for lighting, having a potential of 236 volts between the outside conductors, and 118 volts between the neutral and either outside conductor.



6,000 H. P. ALLIS-CHALMERS ENGINE. DIRECT-CONNECTED TO GENERATOR.

Carries 6,000 H. P. with 15 inches vacuum.

Machinery Hall, World's Fair, St. Louis.

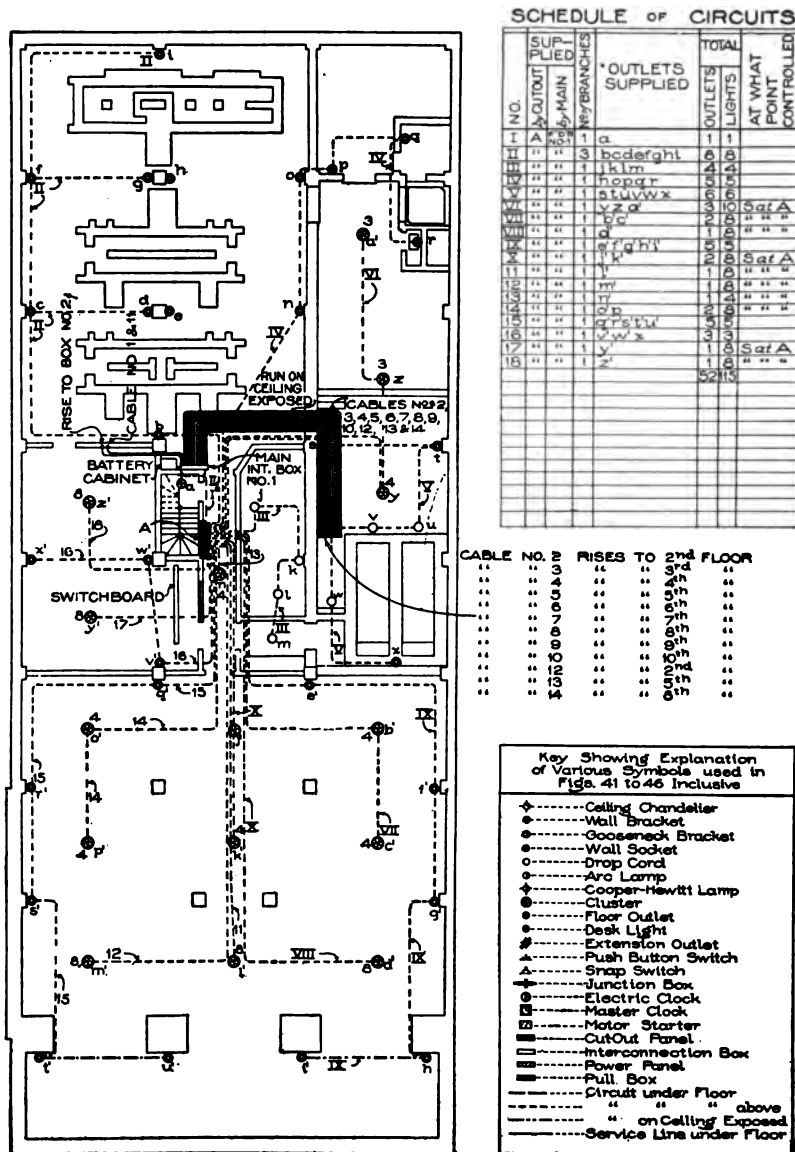
Switchboard. On the switchboard in the basement are mounted wattmeters, provided by the local electric company, and the various switches required for the control and operation of the lighting and power feeders. There are a total of ten triple-pole switches for lighting, and eighteen for power. An indicating voltmeter and ampere meter are also placed in the switchboard. A voltmeter is provided with a double-throw switch, and so arranged as to measure the potential across the two outside conductors, or between the neutral conductor and either of the outside conductors. The ampere meter is arranged with two shunts, one being placed in each outside leg; the shunts are connected with a double-pole, double-throw switch, so that the ampere meter can be connected to either shunt and thus measure the current supplied on each side of the system.

Character of Load. The building is occupied partly as a newspaper office, and there are several large presses in addition to the usual linotype machines, trimmers, shavers, cutters, saws, etc. There are also electrically-driven exhaust fans, house pumps, air-compressors, etc. The upper portion of the building is almost entirely devoted to offices rented to outside parties. The total number of motors supplied was 55; and the total number of outlets, 1,100, supplying 2,400 incandescent lamps and 4 arc lamps.

Feeders and Mains. The arrangement of the various feeders and mains, the cut-out centers, mains, etc., which they supply, are shown diagrammatically in Fig. 41, which also gives in schedule the sizes of feeders, mains, and motor circuits, and the data relating to the cut-out panels.

Although the current supply was to be taken from an outside source, yet, inasmuch as there was a probability of a plant being installed in the building itself at some future time, the three-wire system of feeders and mains was designed, with a neutral conductor equal to the combined capacity of the two outside conductors, so that 120-volt two-wire generators could be utilized without any change in the feeders.

Basement. The plan of the basement, Fig. 42, shows the branch circuit wiring for the outlets in the basement, and the location of the main switchboard. It also shows the trunk cables for the inter-connection system serving to provide the necessary wires for telephones,



tickers, messenger calls, etc., in all the rooms throughout the building, as will be described later.

To avoid confusion, the feeders were not shown on the basement plan, but were described in detail in the specification, and installed in accordance with directions issued at the time of installation. The electric current supply enters the building at the front, and a service switch and cut-out are placed on the front wall. From this point, a two-wire feeder for power and a three-wire feeder for lighting, are run to the main switchboard located near the center of the basement. Owing to the size of the conduits required for these supply feeders, as well as the main feeders extending to the upper floors of the building, the said conduits are run exposed on substantial hangers suspended from the basement ceiling.

First Floor. The rear portion of the building from the basement through the first floor, Fig. 43, and including the mezzanine floor, between the first and second floors, at the rear portion of the building only, is utilized as a press room for several large and heavy, modern newspaper presses. The motors and controllers for these presses are located on the first floor. A separate feeder for each of these press motors is run directly from the main switchboard to the motor controller in each case. Empty conduits were provided, extending from the controllers to the motor in each case, intended for the various control wires installed by the contractor for the press equipments.

One-half of the front portion of the first floor is utilized as a newspaper office; the remaining half, as a bank.

Second Floor. The rear portion of the second floor, Fig. 44, is occupied as a composing and linotype room, and is illuminated chiefly by means of drop-cords from outlets located over the linotype machines and over the compositors' cases. Separate $\frac{1}{8}$ -horse-power motors are provided for each linotype machine, the circuits for the same being run underneath the floor.

Upper Floors. A typical plan (Fig. 45) is shown of the upper floors, as they are similar in all respects with the exception of certain changes in partitions, which are not material for the purpose of illustration or for practical example. The circuit work is sufficiently intelligible from the plan to require no further explanation.

Interconnection System. Fig. 46 is a diagram of the interconnection system, showing the main interconnection box located in the

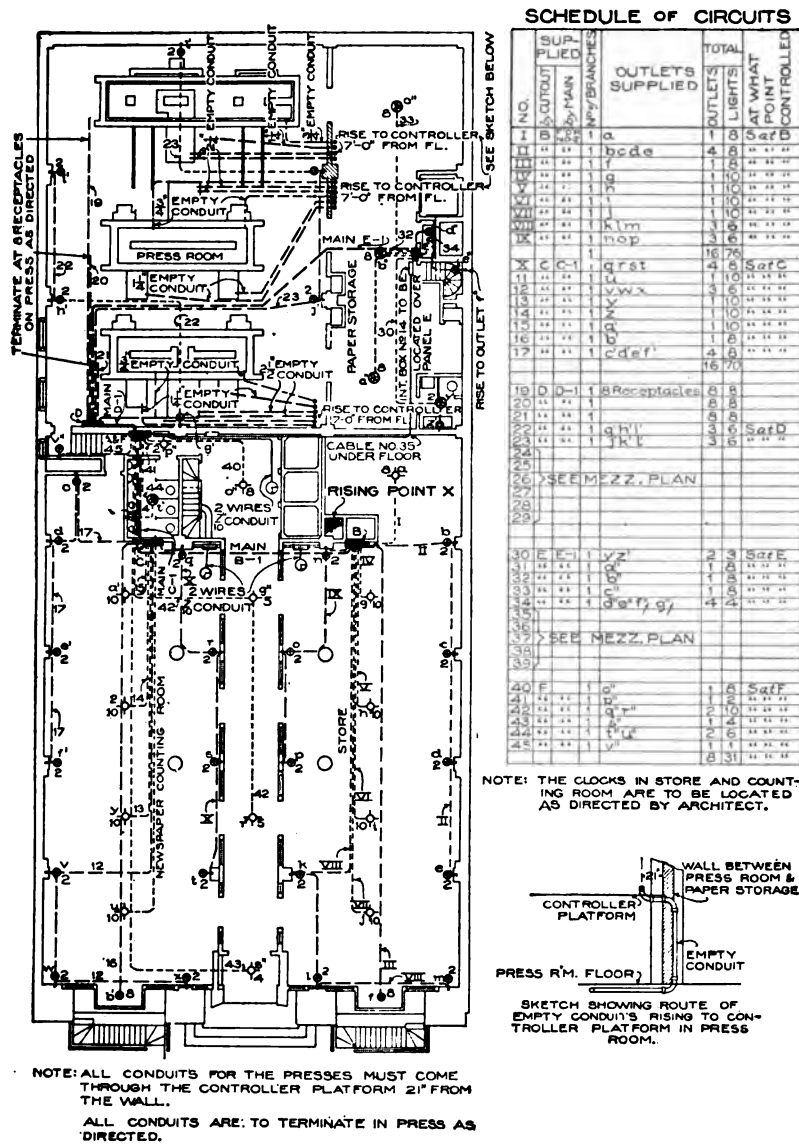


Fig. 43. Wiring of an Office Building.
First-Floor Plan, Showing Press Room in Rear, Containing Motors and Controllers for Newspaper Presses, Fed Directly from Main Switchboard in Basement; also, in front, Newspaper Counting Room and Bank Offices.

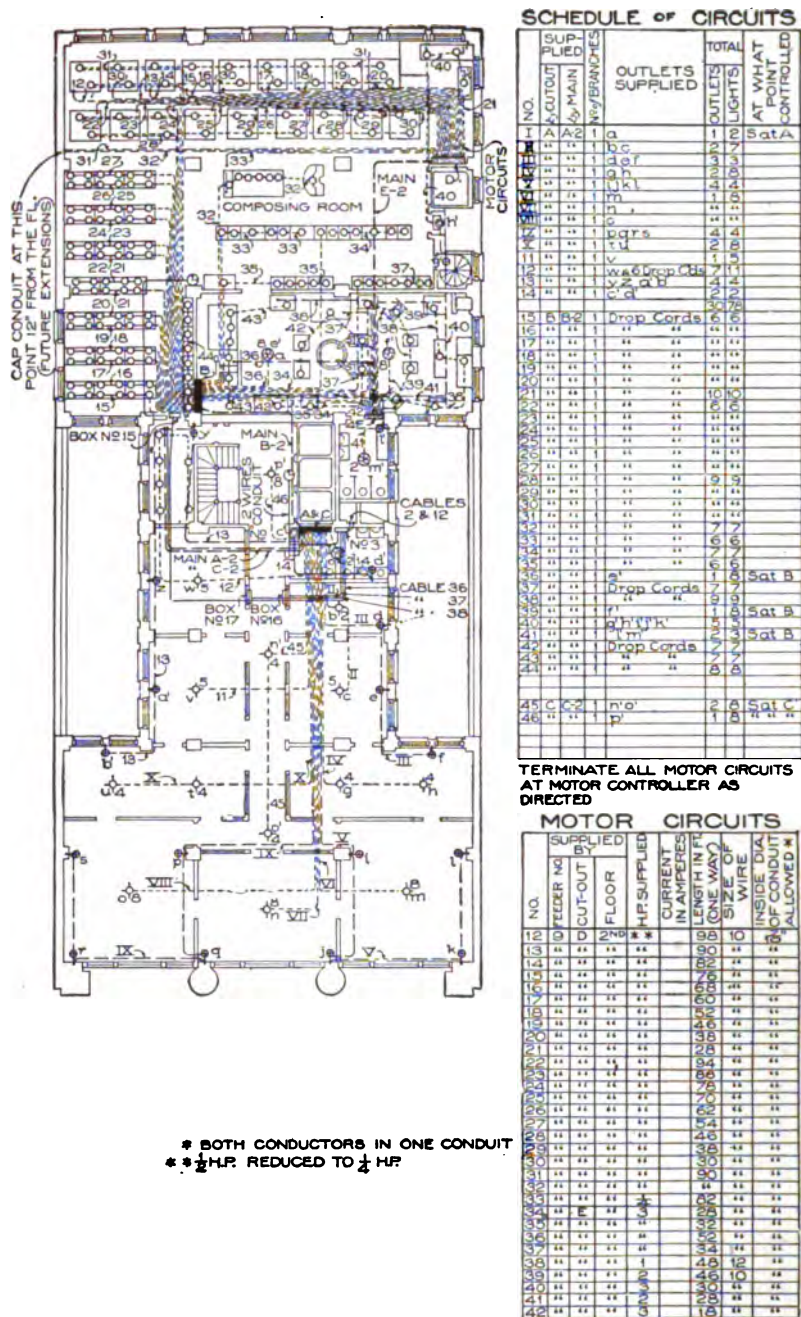


Fig. 44. Wiring of an Office Building. Plan of Second Floor. Rear Portion Occupied as a Composing and Linotype Room.

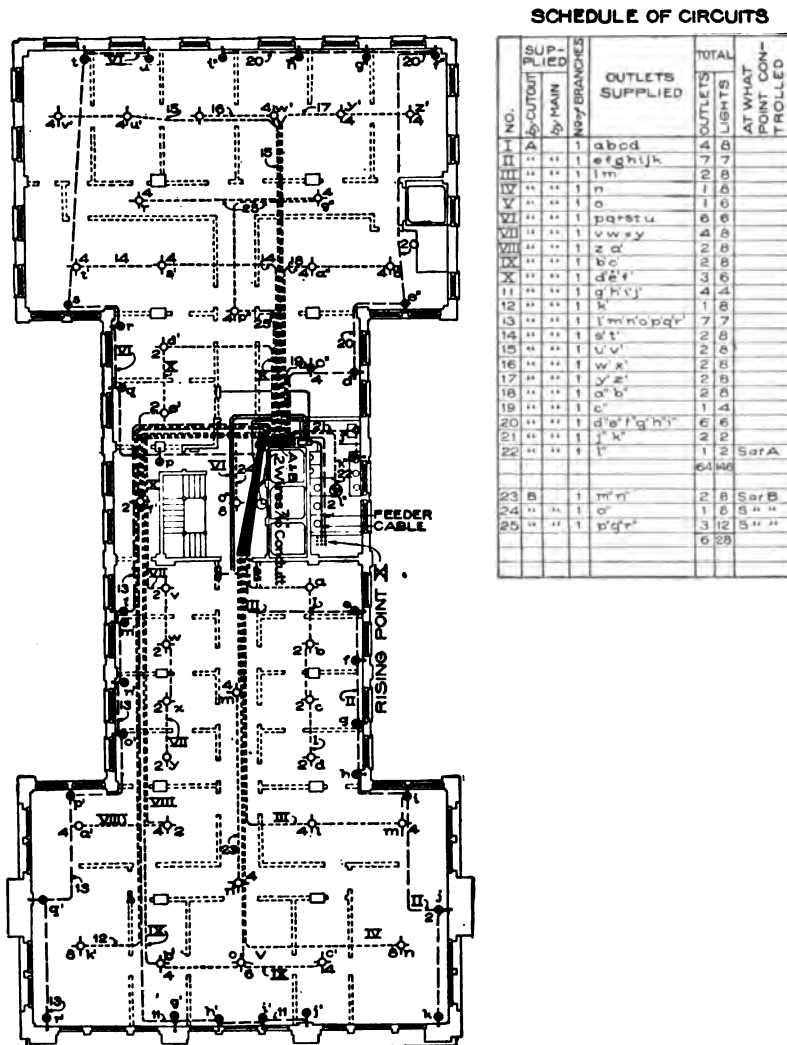


Fig. 45. Wiring of an Office Building.

Typical Plan of Upper Floors, Showing Circuit Work, Schedule, etc. All the Floors above the Second are Similar to One Another in Plan, Differing Only in Comparatively Unimportant Details of Partitions.

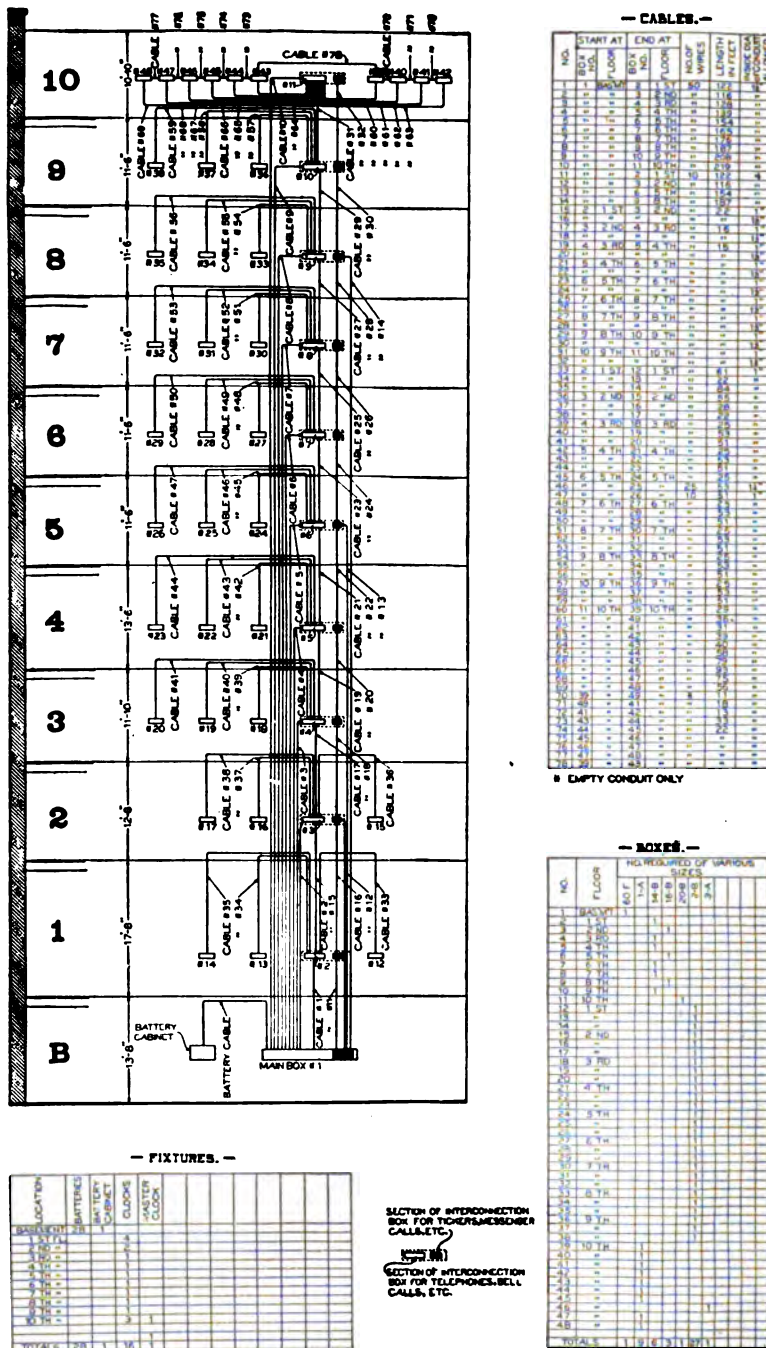


Fig. 46. Wiring of an Office Building. Diagram of the Interconnection System.

basement; adjoining this main box is located the terminal box of the local telephone company. A separate system of feeders is provided for the ticker system, as these conductors require somewhat heavier insulation, and it was thought inadvisable to place them in the same conduits with the telephone wires, owing to the higher potential of ticker circuits. A separate interconnection cable runs to each floor, for telephone and messenger call purposes; and a central box is placed near the rising point at each floor, from which run subsidiary cables to several points symmetrically located on the various floors. From these subsidiary boxes, wires can be run to the various offices requiring telephone or other service. Small pipes are provided to serve as race-ways from office to office, so as to avoid cutting partitions. In this way, wires can be quickly provided for any office in the building without damaging the building in any way whatever; and, as provision is made for a special wooden moulding near the ceiling to accommodate these wires, they can be run around the room without disfiguring the walls. All the main cables and subsidiary wires are connected with special interconnection blocks numbered serially; and a schedule is provided in the main interconnection box in the basement, which enables any wire originating thereat, to be readily and conveniently traced throughout the building. All the main cables and subsidiary cables are run in iron conduits.

OUTLET-BOXES, CUT-OUT PANELS, AND OTHER ACCESSORIES

Outlet-Boxes. Before the introduction of iron conduits, outlet-boxes were considered unnecessary, and with a few exceptions were not used, the conduits being brought to the outlet and cut off after the walls and ceilings were plastered. With the introduction of iron conduits, however, the necessity for outlet-boxes was realized; and the *Rules* of the Fire Underwriters were modified so as to require their use. The *Rules of the National Electric Code* now require outlet-boxes to be used with rigid iron and flexible steel conduits, and with armored cables. A portion of the rule requiring their use is as follows:

All interior conduits and armored cables "must be equipped at every outlet with an approved outlet-box or plate.

"Outlet-plates must not be used where it is practicable to install outlet-boxes.

"In buildings already constructed, where the conditions are such that neither outlet-box nor plate can be installed, these appliances may be omitted by special permission of the inspection department having jurisdiction, providing the conduit ends are bushed and secured."

Fig. 47 shows a typical form of outlet-box for bracket or ceiling outlets of the *universal type*. When it is desired to make an opening

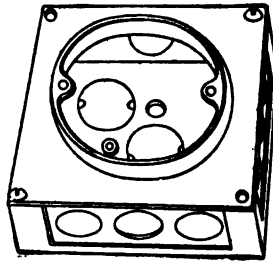


Fig. 47. Universal and Knock-Out Type of Outlet Box.

for the conduits, a blow from a hammer will remove any of the weakened portion of the wall of the outlet-box, as may be required. This form of outlet-box is frequently referred to as the *knock-out type*. Other forms of outlet-boxes are made with the openings cast in the box at the required points, this class being usually stronger and better made than the universal type. The advantages of the universal

type of outlet-box are that one form of box will serve for any ordinary conditions, the openings being made according to the number of conduits and the directions in which they enter the box.

Fig. 48 shows a waterproof form of outlet-box used out of doors, or in other places where the conditions require the use of a water-tight and waterproof outlet-box.

It will be seen in this case, that the box is threaded for the con-

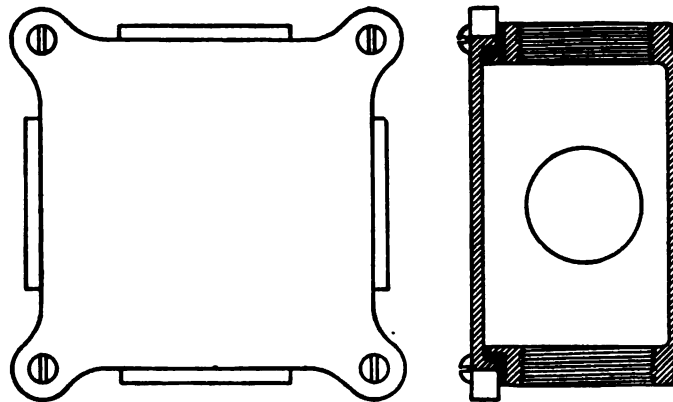


Fig. 48. Water-Tight Outlet Box.
Courtesy of H. Krantz Manufacturing Co., Brooklyn, N. Y.

duits, and that the cover is screwed on tightly and a flange provided for a rubber gasket.

Figs. 49 and 50 show water-tight floor boxes which are for outlets located in the floor. While the rules do not require that the floor outlet-box shall be water-tight, it is strongly recommended that a water-tight outlet be used in all cases for floor connections. In this case also, the conduit opening is threaded, as well as the stem cover through which the extension is made in the conduit to the desk or table. When the floor outlet connection is not required, the stem cover may be removed and a flat, blank cover be used to replace the same.

A form of outlet-box used for flexible steel cables and steel armored cable, has already been shown (see Fig. 5).

There is hardly any limit to the number and variety of makes of outlet-boxes on the market, adapted for ordinary and for special con-

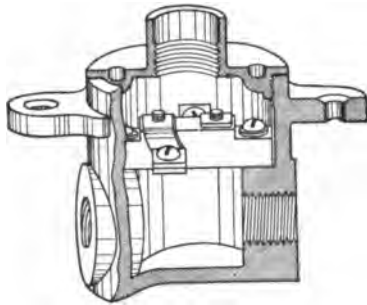


Fig. 49.

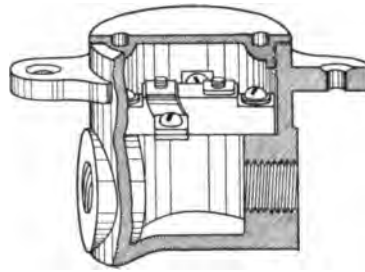


Fig. 50.

Types of Floor Outlet-Boxes.

ditions; but the types illustrated in these pages are characteristic and typical forms.

Bushings. The *Rules of the National Electric Code* require that conduits entering junction-boxes, outlet-boxes, or cut-out cabinets, shall be provided with approved *bushings*, fitted to protect the wire from abrasion.

Fig. 51 shows a typical form of conduit bushing. This bushing is screwed on the end of the conduit after the latter has been introduced into the outlet-box, cut-out cabinet, etc., thereby forming an insulated orifice to protect the wire at the point where it leaves the conduits, and to prevent abrasion, grounds, short circuits, etc. A lock-nut (Fig. 52) is screwed on the threaded end of the conduit before the conduit is placed in the outlet-box or cut-out cabinet, and this lock-nut and bushing clamp the conduit securely in position. Fig.

53 shows a terminal bushing for panel-boxes used for flexible steel conduit or armored cable.

The *Rules of the National Electric Code* require that the metal of conduits shall be permanently and effectually grounded, so as to

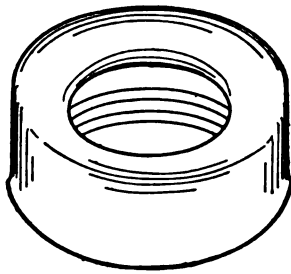


Fig. 51. Conduit Bushing.

insure a positive connection for grounds or leaking currents, and in order to provide a path of least resistance to prevent the current from finding a path

through any source which might cause a fire. At outlet-boxes, the conduits and gaspipes must be fastened in such a manner as to insure good electrical connection; and at centers of distribution,

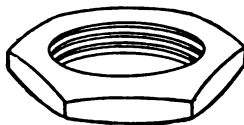


Fig. 52. Lock-Nut.

the conduits should be joined by suitable bond wires, preferably of copper, the said bond wires being connected to the metal structure of the building, or, in case of a building not having an iron or steel structure, being grounded in a permanent manner to water or gas piping.

Fuse-Boxes, Cut-Out Panels, etc. From the very outset, the necessity was apparent of having a protective device in circuit with the conductor to protect it from overload, short circuits, etc. For this purpose, a fusible metal having a low melting point was employed. The form of this fuse has varied greatly. Fig. 54 shows a characteristic form of what is known as the *link fuse* with copper terminals, on which are stamped the capacity of the fuse.



Fig. 53. Panel-Box Terminal Bushing.
Courtesy of Sprague Electric Co., New York, N. Y.

The form of fuse used probably to a greater extent than any other, although it is now being superseded by other more modern forms,

is that known as the *Edison fuse-plug*, shown in Fig. 55. A porcelain *cut-out block* used with the Edison fuse is shown in Fig. 56.

Within the last four or five years, a new form of fuse, known as the *enclosed fuse*, has been introduced and used to a considerable

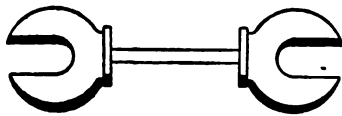


Fig. 54. Copper-Tipped Fuse Link.



Fig. 55. Edison Fuse-Plug.

Courtesy of General Electric Co., Schenectady, N. Y.

extent. A fuse of this type is shown in Fig. 57. Fig. 58 gives a sectional view of this fuse, showing the porous filling surrounding the fuse-strips, and also the device for indicating when the fuse has blown. This form of fuse is made with various kinds of terminals;



Fig. 56. Porcelain Cut-Out Block.
*Courtesy of General Electric Co.,
Schenectady, N. Y.*

it can be used with spring clips in small sizes, and with a post screw contact in larger sizes. For ordinary low potentials this fuse is desirable for currents up to 25 amperes; but it is a debatable question whether it is desirable to use an enclosed fuse for heavier currents. Fig. 59 shows a *cut-out box* with Edison plug

fuse-blocks used with knob and tube wiring. It will be seen that there is no connection compartment in this fuse-box, as the circuits enter directly opposite the terminals with which they connect.

Fig. 60 shows a *cut-out panel* adapted for enclosed fuses, and installed in a cabinet having a connection compartment. As will be seen from the cut, the tablet itself is surrounded on the four sides by slate,

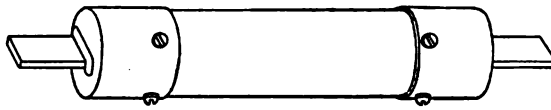


Fig. 57. Enclosed or "Cartridge" Fuse.



Fig. 58. Section of Enclosed Fuse.

which is secured in the corners by angle-irons. The outer box may be of wood lined with sheet iron, or it may be of iron. Fig. 61 shows a door and trim for a cabinet of this type. It will be seen that

the door opens only on the center panel, and that the trim covers and conceals the connection compartment. The inner side of the door should be lined with slate, and the inner side of the trim should be lined with sheet iron. Fig. 62 shows a sectional view of the cabinet and panel. In this type of cabinet, the conduits may enter at any

point, the wires being run to the proper connectors in the connection compartment.

Figs. 63 and 64 illustrate a type of panel-board and cabinet having a push-button switch connected with each branch circuit and so arranged that the cut-out panel itself may be enclosed by locked doors, and access to the switches may be obtained through two separate doors provided with latches only.

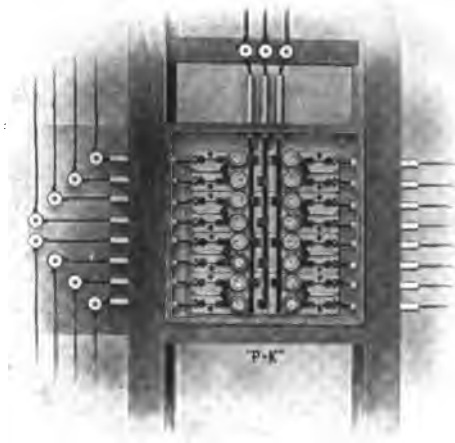


Fig. 59. Porcelain Cut-Outs in Wooden Box.
Courtesy of H. T. Paiste Co., Philadelphia, Pa.

This type of panel was arranged and designed by the author of this instruction paper.

OVERHEAD LINWORK

The advantages of overhead linework as compared with underground linework are that it is much less expensive; it is more readily and more quickly installed; and it can be more readily inspected and repaired.

Its principal disadvantages are that it is not so permanent as underground linework; it is more easily deranged; and it is more unsightly.

For large cities, and in congested districts, overhead linework should not be used. However, the question of first cost, the question of permanence, and the municipal regulations, are usually the factors which determine whether overhead or underground linework shall be used.

The principal factors to be considered in overhead linework will be briefly outlined.

Placing of Poles. As a general rule, the poles should be set from 100 to 125 feet apart, which is equivalent to 53 to 42 poles per mile. Under certain conditions, these spacings given will have to be modified; but if the poles are spaced too far apart, there is danger of too great a strain on the poles themselves, and on the cross-arms, pins, and

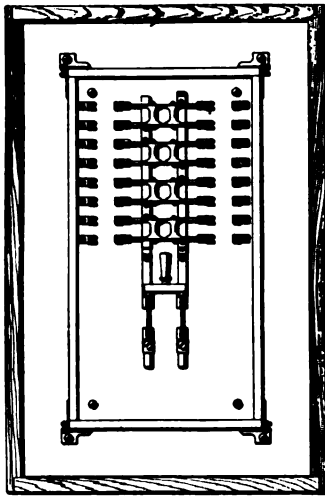


Fig. 60. Plan View, Cover, and Section of Double Cut-Out Box.

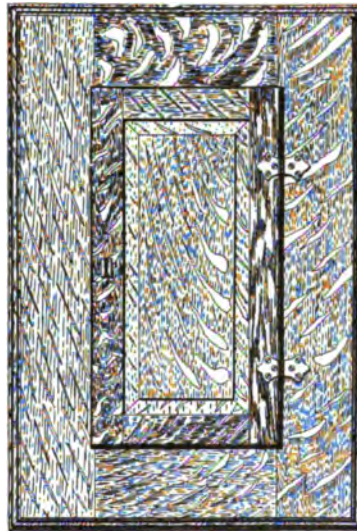


Fig. 61.

conductors. If, on the other hand, they are placed too close together, the cost is unnecessarily increased. The size and number of conductors, and the potential of the line-work, determine to a great extent



Fig. 62.

the distance between the poles; the smaller the size, the less the number of conductors; and the lower the potential, the greater the distance between the poles may be made. Of course, the exact location of the poles is subject to variation because of trees, buildings, or other obstructions. The usual method employed in locating poles, is first to make a map on a fairly large scale, showing the course of the line-work, and then to locate the poles on the ground according to the actual conditions.

Poles. Poles should be of selected quality of chestnut or cedar, and should be sound and free from cracks, knots, or other flaws. Experience has proven that chestnut and cedar poles are the most durable and best fitted for linework. If neither chestnut nor cedar poles can be obtained, northern pine may be used, and even other timber in localities where these poles cannot be obtained; but it is found that the other woods do not last so long as those mentioned,

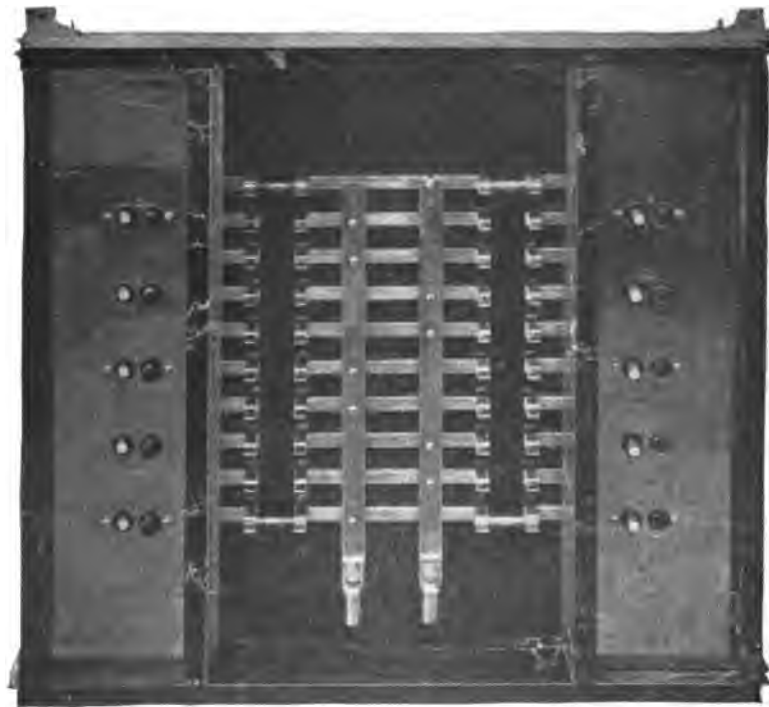


Fig. 68. Cut-Out Panel with Push-Button Switches. Cover Removed.

and some of the other woods are not only less strong initially, but are apt to rot much quicker at the "wind and water line"—that is, just above and below the surface of the ground.

The proper height of pole to be used depends upon conditions. In country and suburban districts, a pole of 25 to 30 feet is usually of sufficient height, unless there are more than two or three cross-arms required. In more densely populated districts and in cities where a great number of cross-arms are required, the poles may have to be



COPPER WIRE BRAZING FURNACE.
Rockwell Engineering Co.

40 to 60 feet, or even longer. Of course, the longer the pole, the greater the possibility of its breaking or bending; and as the length increases, the diameter of the butt end of pole should also increase. Table X gives the average diameters required for various heights of poles, and the depth the poles should be placed in the ground. These data have been compiled from a number of standard specifications.

TABLE X
Pole Data

LENGTH OF POLE	DIAMETER 6 IN. FROM BUTT	DIAMETER AT TOP	DEPTH POLE SHOULD BE PLACED IN GROUND
25 feet	9 to 10 in.	6 to 8 in.	5 feet
30 "	11 "	"	5½ "
35 "	12 "	"	5½ "
40 "	13 "	"	6 "
45 "	14 "	"	6½ "
50 "	15 "	"	7 "
55 "	16 to 17 "	"	7½ "
60 "	18 "	"	7½ "
65 "	19 "	"	8 "
70 "	20 "	"	8 "
75 "	21 "	"	8½ "
80 "	22 "	"	9 "

As it is somewhat difficult, because of irregularities in size, to measure the diameter of some poles, the circumference may be measured instead: then, by multiplying the diameters given in the above table, by 3.1416, the measurements may be reduced to the circumference in inches.

The minimum diameters of the pole at the top, which should be allowed, will depend largely on the size of the conductors used, and on the potential carried by the circuits; the larger the conductors and the higher the potentials, the greater should be the diameter at the top of the pole.

Poles should be shaved, housed, and gained, also cleaned and ready for painting, before erection.

Poles should usually be painted, not only for the sake of appearance, but also in order to preserve them from the weather. It is particularly important that they should be protected at their butt end, not only where they are surrounded by the ground, but for a foot or two above the ground, as it is at this point that poles usually deteriorate most rapidly. Painting is not so satisfactory at this point as the use of tar; pitch, or creosote. The life of the pole can be increased considerably by treating it with one or another of these preservatives.

Before any poles are erected, they should be closely inspected for flaws and for crookedness or too great departure from a straight line.

Where appearance is of considerable importance, octagonal poles may be used, although these cost considerably more than round poles. *Gains* or notches for the cross-arms should be cut in the poles before they are erected, and should be cut square with the axis of the pole, and so that the cross-arms will fit snugly and tightly within the space thus provided. These gains should be not less than $4\frac{1}{2}$ inches wide,



Fig. 64. Cut-Out Panel with Push-Button Switches. With Cover.

nor less than $\frac{1}{2}$ inch deep. Gains should not be placed closer than 24 inches between centers, and the top gains should be at least 9 inches from the apex of the pole

ELECTRIC BELL WIRING.

In wiring for electric bells to be operated by batteries, the danger of causing fires from short circuits or poor contacts does not exist as in the case of wiring for light and power, because the current strength is so small. Neither is the bell-fitter responsible to city inspectors or fire underwriters. On this account, bell fitting is too often done in a careless and slovenly manner, causing the apparatus to give unsatisfactory results and to require frequent repairs, so that the expense and inconvenience in the end far more than offset any time saved by doing an inferior grade of work. Hence, at the outset it is well to state that as much care should be taken in the matter of joints and insulation of bell wiring as in wiring for light or power.

If properly installed, the electric bell forms a reliable and yet inexpensive means of signaling, and is far superior to any other. On this account practically every new building is fitted throughout with electric bells.

In addition to the necessity of thoroughness already mentioned, care should be taken to use only reliable apparatus which must be installed in accordance with the fundamental principles on which its satisfactory operation depends.

WIRE.

The common sizes of wire in use for bell work are Nos. 18, 20, and 22. In general, however, No. 20 will be found satisfactory as it is usually sufficiently large, while in many cases No. 22 is not strong enough from a mechanical standpoint.

It is important that the wires should be well insulated to pre-



Fig. 1.

vent accidental contacts with the staples or other wires. First of all the wire should be tinned, as this prevents the copper from being acted upon by the sulphur in the insulation. It also facilitates soldering. The inner coating of insulation should be of

india rubber, surrounded by several longitudinal strands of cotton, outside of which are wound several strands of colored cotton laid on spirally. This is next immersed in melted paraffin wax and polished by friction. A short length of approved electric bell wire is shown in Fig. 1.

When ordering wire, it is well to have it furnished in several different colors as this greatly facilitates both the original installation and later repairs, because in this way one line may be distinguished from another, taps from main lines, etc. Moreover, a faulty wire having been found, it is possible to identify it at any desired section of its length.

METHODS OF WIRING.

In running wires, the shortest and most direct route should, of course, be taken between the battery, bells, and bell pushes. There are two cases to be considered. The better method is that in which the wires are run before the building is completed, and the wiring should be done as soon as the roof is on and the walls are up. In this case the wires are usually run in zinc tubes secured to the walls with nails. The tubes should be from $\frac{3}{8}$ inch

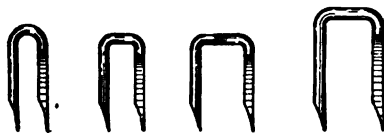


Fig. 2.

to $\frac{1}{2}$ inch in diameter, preferably the latter. It is better to place the wires and tubes simultaneously, but the tubes may be put in place first and the wires drawn in afterward, although this latter

plan has the objection that the insulation is liable to become abraded when the wires are drawn in. In joining up two lengths of tube, the end of one piece should be opened up with the pliers so that it may receive the end of the other tube, which should also be opened up, but to a less extent, to prevent wear upon the insulation. Specially prepared paper tubes are sometimes substituted for the zinc.

If the building is completed before the wiring is done, the concealed method described above cannot be used, and it is necessary to run the wires along the walls supported by staples, where they will be least conspicuous. Fig. 2 shows ordinary double-pointed tacks, Fig. 3 shows an insulating saddle staple which

is to be recommended. Two wires should never be secured under the same staple if it can possibly be avoided, owing to the danger of short circuits. With a little care it is usually possible to conceal the wiring behind the picture moulding, along the skirting-board, and beside the door posts, but where it is impossible to conceal it, a light ornamental casing to match the finish of the room, may be used.

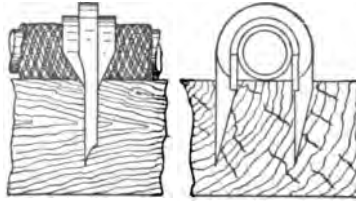


Fig. 3.

It is sometimes advisable to use twin wires or two insulated wires run in the same outer covering.

In some cases it is well to run the wires under the floors, laying them in notches in the tops of the joists or in holes bored about two inches below the tops of the joists.

JOINTS.

When making a joint, care should be taken to have a firm, clean connection, both mechanically and electrically, and this must always be soldered to prevent corrosion. The insulation should be stripped off the ends of the wires to be joined, for a distance of about 2 inches, and the wires made bright by scraping or sandpa-



Fig. 4.

pering. They should then be twisted tightly and evenly together as shown in Fig. 4.

Next comes the operation of **soldering**, which is absolutely necessary if a permanent joint from an electrical standpoint is to be obtained. A joint made without solder may be electrically sound at first, but its resistance rapidly increases, due to deterioration of the joint. As has already been stated, the wires should be made bright and clean before they are twisted together. Soldering fluids should never be used, because they cause corrosion of the wire. The best flux to use is resin or composite candle. The soldering should always be done with a copper bit rather than with a blowpipe or wireman's torch.

A convenient form of soldering tool consists of a small copper bit having a semicircular notch near the end. This bit should, of course, be well tinned. It is then heated over a spirit lamp, or wireman's torch, and the notch filled with soft solder. Lay the joint, which has previously been treated with the flux, in this notch and turn it so that the solder runs completely around among the spirals of the joint. The loose solder should be shaken off or removed with a bit of rag. When the joint is set, it should be insulated with rubber tape, so that it will be protected as perfectly as the other portions.

It is often possible to save a considerable length of wire and amount of labor by using a ground return, which, if properly arranged, will give very satisfactory results, although a complete metallic circuit is always to be preferred. Where water or gas

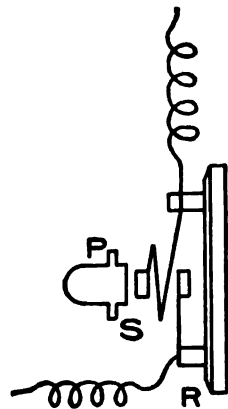


Fig. 5.

mains are available, a good ground may be obtained by connecting to them, being sure to have a good connection. This may be secured by scraping a portion of the pipe perfectly bright and clean and then winding this with bare wire; the whole is then well soldered. An end should be left to which the wire from the bell circuit is twisted and soldered. If such mains are not available, a good ground can be obtained by connecting the wire from the bell circuit, as described above, to a pump pipe. In the absence of water and gas mains, and of a pump pipe, a ground may be obtained by burying beneath permanent moisture level a sheet of copper

or lead, having at least five square feet of surface, to which the return wire is connected. The ground plate should be covered with coke nearly to the surface; the hole should then be filled in with ordinary soil well rammed.

OUTFIT.

The three essential parts of the electric bell outfit are the bell push, which furnishes a means of opening and closing the circuit at will, the battery, which furnishes the current for operating the

bell, and the bell itself. Before discussing the combination of these pieces of apparatus in the complete circuit, let us take up the individual parts in order.

A bell push is shown diagrammatically in Fig. 5. In this illustration P is the push button; when this is pressed upon it brings the point of the spring S in contact with the metal strip R, thus closing the circuit with which it is connected in series. Normally the springs are separated as shown, and the circuit is accordingly open.

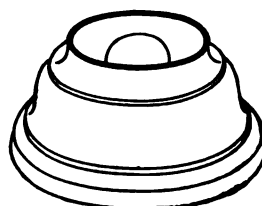


Fig. 6.

Bell pushes are made in various designs and styles, from the simple wooden push shown in Fig. 6 to very elaborate and expensive articles. Fig. 7 shows four cast bronze pushes of neat appearance and moderate price.

Batteries. Electric bells are nearly always operated on the open circuit plan, and hence the battery used is generally of the

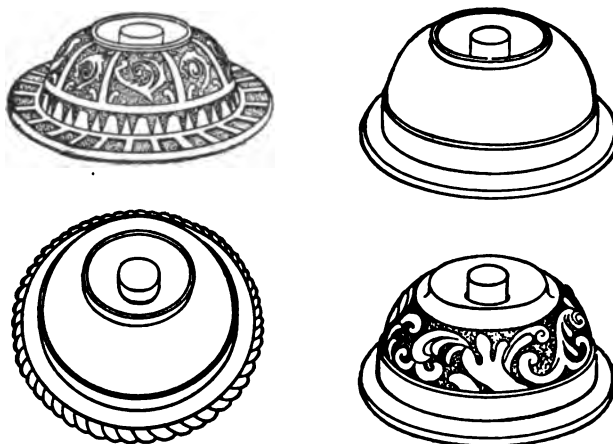


Fig. 7.

open circuit type, such as the Leclanche cell, which is used very largely except for heavy work. This is a zinc-carbon cell in which the excitant is sal-ammoniac dissolved in water. Polarization is prevented by peroxide of manganese, which gives up part of its oxygen, combining with the hydrogen set free and forming water.

Dry Batteries are also frequently used for bell work, their principal advantage being cleanliness, as they cannot spill. Dry cells are really a modification of the Leclanche type, as they use zinc and carbon plates and sal-ammoniac as the exciting agent. The Burnley cell, which is one of the principal types of dry cell, has an electrolyte composed of sal-ammoniac, chloride of zinc, plaster, flour, and water. This compound when mixed is a semi-liquid mass which quickly stiffens after being poured into the cup. The depolarizing agent is peroxide of manganese, the same as is used in the Leclanche cell, this being packed around the carbon cylinder. The top of the cell is sealed with bitumen or some similar substance.

For very heavy work the Edison-Lalande and the Fuller types of cell are best suited, while for closed circuit work the gravity cell is most satisfactory.

Bell. It is a well-known fact that if a current of electricity flows through a coil of wire wound on an iron coré, the core becomes magnetized and is capable of attracting any magnetic substances to itself. The operation of the electric bell, like that of so many other pieces of electrical apparatus, depends upon this fact. A diagrammatic representation of an electric bell is shown in

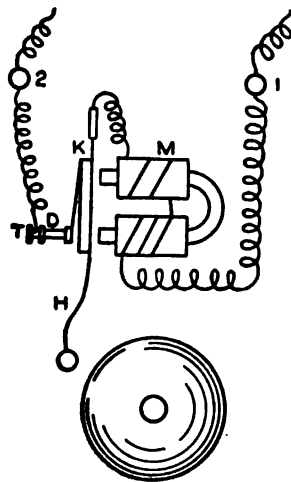


Fig. 8.

Fig. 8, in which M is an electromagnet composed of soft-iron cores on which are wound coils of insulated wire. The armature is mounted upon a spring K, and carries a hammer H at its end for striking the gong. On the back of the armature is a spring which makes contact at D with the back stop T. The action of the bell is as follows: When the circuit is closed through the bell a current flows from terminal 1, around the coils of the magnet, through the spring K and contact point D, through the back stop T, to terminal 2. In flowing around the electromagnet the current magnetizes its core, which consequently attracts the armature. This causes the hammer H to strike the gong. While in this position the contact at D is broken, the current ceases to flow

around the electromagnet and the cores consequently lose their attractive force. The armature is then carried back to its original position by the spring K, making contact at D, and the process is repeated. The hammer will thus vibrate and the bell continue to ring as long as the circuit is closed.

The type of bell described above is the one most commonly used. Such bells are made in a great variety of shapes and styles, the prices varying accordingly. It is important that platinum tips be furnished at the contact point D, Fig. 8, to prevent cor-

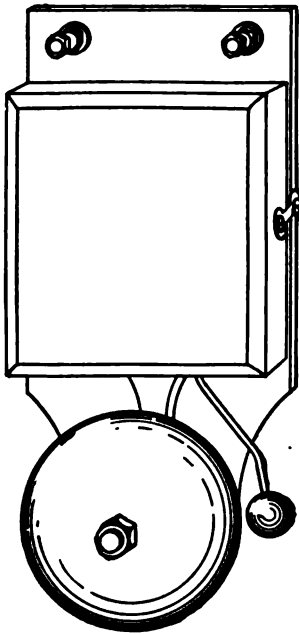


Fig. 9.

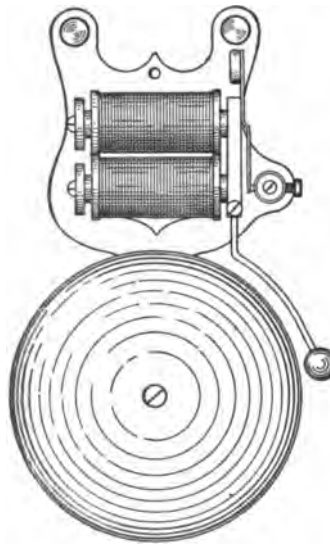


Fig. 10.

rosion. The bells on the market today are of two classes, the iron box bell and the wooden box bell. A bell of the wooden box type is shown in Fig. 9, and a higher grade bell of the iron frame skeleton type is shown in Fig. 10. Bells without covers should never be used, as dust will settle on the contacts and interfere with their action.

CIRCUITS.

The possible combinations of the various parts into complete circuits are so varied that it would be impossible to describe them

all; in fact, almost every one is to a certain extent a special problem. It is, however, possible to give typical circuits the underlying principles of which can be applied successfully to any particular case.

Fig. 11 shows a bell circuit in its simplest form, in which P represents the push, B the bell, and C the battery; all connected in series. The circuit is normally open at P, and hence no current flows to exhaust the batteries.

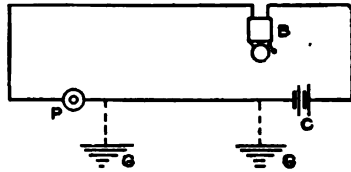


Fig. 11.

When P is pressed, the circuit, otherwise complete, is closed and current passes through the bell causing it to ring, as already explained. For instance, the push might be located beside the front door, the bell in the kitchen and the

battery in the cellar; the location depending on the results desired and conditions to be met. The wire between P and C may, if necessary, be dispensed with and connection made to ground at G and G, as shown by the dotted lines.

Fig. 12 shows an arrangement by means of which one bell B

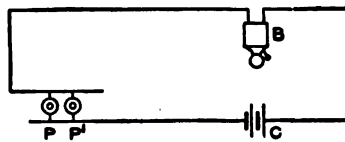


Fig. 12.

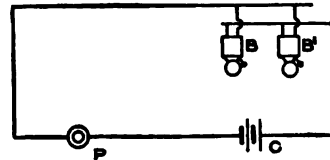


Fig. 13.

may be controlled by either of the pushes P or P'. This system may be extended to any number of pushes similarly connected.

A method for ringing two bells simultaneously from one push is shown in Fig. 13, where both bells B and B' will ring from push P. Bells, if connected in this manner, should have as nearly as possible the same resistance, otherwise the bell of lower resistance will take so much current that there will not be a sufficient amount left for the other. Also, the batteries must be of greater current capacity as the amount of current taken is, of course, doubled. This system can be extended to any number of bells connected in this way, up to the limit of capacity of the battery to ring them. Figs.

12 and 13 may be combined so that two or more bells may be rung from any one of two or more pushes.

In Fig. 14 is shown a scheme for ringing either bell, B or B', from one push and one battery by means of the two-point switch

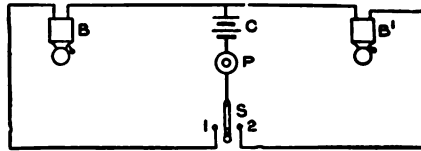


Fig. 14.

S. When the arm of the switch is on contact 1, the push will ring bell B, and when on contact 2 it will ring bell B'.

In Fig. 15 is shown a method of connecting bells in series so that B and B' may be rung from P. If all the bells so connected were of the vibrating type, they would not work satisfactorily, as it would be impossible to time them so that the vibrations would keep step, hence only one bell should be of the vibrating type, and the others should have the circuit breakers short-circuited, the vibrating bell serving as interrupter for the whole series. Obviously this system requires a higher volt-

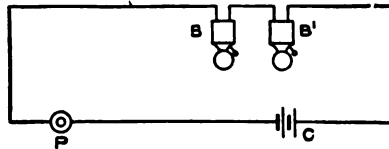


Fig. 15.

age than parallel connection, and the cells must be of sufficient E.M.F. to ring the bells satisfactorily. Several bells may be connected in this way, if desired, up to the limit of voltage of the battery.

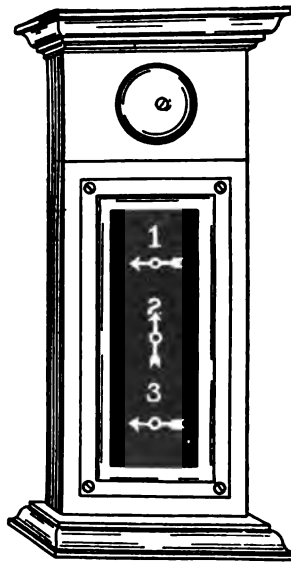


Fig. 16.

Oftentimes a bell is to be rung from several different places. For instance, the bell in an elevator may be rung from any one of

several floors, or the bell in the office of a hotel may be rung from any one of several different rooms. In this case it is necessary to have some device to indicate from which push the bell was rung. The annunciator furnishes this information very well. A three-station annunciator is shown in Fig. 16. The connections for an annunciator are shown in Fig. 17 where A represents the annunciator, B the bell, C the battery, and P^1 , P^2 , and P^3 the pushes. For instance, when P^1 is pressed, the current passes through the electromagnet controlling point 1 on the annunciator which causes

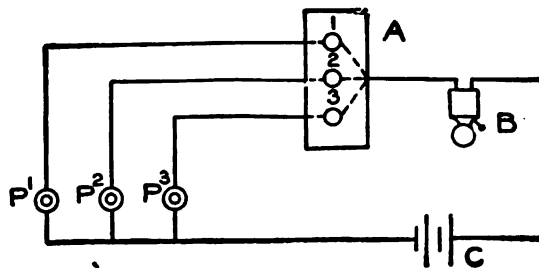


Fig. 17.

the arrow to be turned and at the same time the bell rings. After the attendant has noted the signal, the arrow is restored to its normal position by pressing a lever on the bottom of the annunciator box.

The electric burglar alarm furnishes a very efficient protection and is an application of the principles already described. The circuit, instead of being completed by a push, is completed by contacts placed on the doors or windows so that the opening of either will cause the bell to ring. The same device may be used on money-drawers, safes, etc.

In the case of the electric fire alarm, the signal may be given either automatically when the temperature reaches a certain degree, or pushes may be placed in convenient locations to be operated manually. The pushes should be protected by glass so that they will not be tampered with, it being necessary to break the glass to give the alarm.



BANK OF COLONIAL TRUST CO., PITTSBURG, PENNA.
Showing Use of Nernst Lamps in Bank and Office Lighting.
Nernst Lamp Co., Pittsburgh, Penna.

ELECTRIC LIGHTING

HISTORY AND DEVELOPMENT

The history of electric lighting as a commercial proposition begins with the invention of the Gramme dynamo, by Z. J. Gramme, in 1870, together with the introduction of the Jablochkoff candle or light, which was first announced to the public in 1876, and which formed a feature of the International Exposition at Paris in 1878. Up to this time, the electric light was known to but few investigators, one of the earliest being Sir Humphrey Davy who, in 1810, produced the first arc of any great magnitude. It was then called the *voltaic arc*, and resulted from the use of two wood charcoal pencils as electrodes and a powerful battery of voltaic cells as a source of current.

From 1840 to 1859, many patents were taken out on arc lamps, most of them operated by clockwork, but these were not successful, due chiefly to the lack of a suitable source of current, since all depended on primary cells for their power. The interest in this form of light died down about 1859, and nothing further was attempted until the advent of the Gramme dynamo.

The incandescent lamp was but a piece of laboratory apparatus up to 1878, at which time Edison produced a lamp using a platinum spiral in a vacuum, as a source of light, the platinum being rendered incandescent by the passage of an electric current through it. The first successful carbon filament was made in 1879, this filament being formed from strips of bamboo. The names of Edison and Swan are intimately connected with these early experiments.

From this time on, the development of electric lighting has been very rapid, and the consumption of incandescent lamps alone has reached several millions each year. When we compare the small amount of lighting done by means of electricity twenty-five years ago with the enormous extent of lighting systems and the numerous applications of electric illumination as they are to-day, the growth and development of the art is seen to be very great, and the value of a study of this subject may be readily appreciated. While in many

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cases electricity is not the cheapest source of power for illumination, its admirable qualities and convenience of operation make it by far the most desirable.

CLASSIFICATION

The subject of electric lighting may be classified as follows:

1. The type of lamps used.
2. The methods of distributing power to the lamps.
3. The use made of the light, or its application.
4. Photometry and lamp testing.

The types of lamps used may be subdivided into:

1. Incandescent lamps: Carbon, metallic filament, Nernst.
2. Special lamps: Exhausted bulb without filament, such as the Cooper-Hewitt lamp and Moore tube lamp.
3. Arc lamps: Ordinary carbon, flaming arc.

INCANDESCENT LAMPS

The *incandescent lamp* is by far the most common type of lamp used, and the principle of its operation is as follows:

If a current I is sent through a conductor whose resistance is R , for a time t , the conductor is heated, and the heat generated $= I^2 R t$, $I^2 R t$ representing joules or watt-seconds.

If the current, material, and conditions are so chosen that the substance may be heated in this way until it gives out light, becomes incandescent, and does not deteriorate too rapidly, we have an incandescent lamp. Carbon was the first successful material to be chosen for this conductor and for ordinary lamps it is formed into a small thread or filament. Very recently metallic filament lamps have been introduced commercially with great success but the carbon incandescent lamp will continue to be used for some time, especially in the low candle-power units operated at commercial voltages. Carbon is a successful material for two reasons:

1. The material must be capable of standing a very high temperature, $1,280^\circ$ to $1,330^\circ$ C., or even higher.
2. It must be a conductor of electricity with a fairly high resistance.

Platinum was used in an early stage of the development, but, as we shall see, its temperature cannot be maintained at a value high enough to make the lamp as efficient as when carbon or a metal



MAST SUSPENSION OF ARC LAMPS.
General Electric Company.

having a melting point higher than that of platinum, is used. Nearly all attempts to substitute another substance in place of carbon have failed until recently, and the few lamps which are entirely or partially successful will be treated later. The nature of the carbon employed in incandescent lamps has, however, been much improved over the first forms, and owing to the still very great importance of this lamp, the method of manufacture will be considered.

Manufacture of Carbon Incandescent Lamps. *Preparation of the Filament.* Cellulose, a chemical compound rich in carbon, is prepared by treating absorbent cotton with zinc chloride in proper proportions to form a uniform, gelatine-like mass. It is customary to stir this under a partial vacuum in order to remove bubbles of air which might be contained in it and destroy its uniformity. This material is then forced, "squirted," through steel dies into alcohol, the

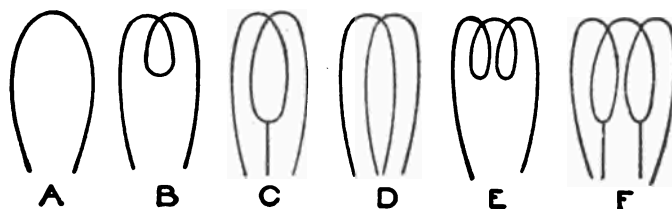


Fig. 1. Forms of Filaments now in Use.

alcohol serving to harden the soft, transparent threads. These threads are then thoroughly washed to remove all trace of the zinc chloride, dried, cut to the desired lengths, wound on forms, and carbonized by heating to a high temperature away from air. During carbonization, the cellulose is transformed into pure carbon, the volatile matter being driven off by the high temperature to which the filaments are subjected. The material becomes hard and stiff, assuming a permanent form, shrinking in both length and diameter—the form being specially constructed so as to allow for this shrinkage. The forms are made of carbon blocks which are placed in plumbago crucibles and packed with powdered carbon. The crucibles, which are covered with loosely fitting carbon covers, are gradually brought to a white heat, at which temperature the cellulose is changed to carbon, and then allowed to cool. After cooling, the filaments are removed, measured, and inspected, and the few defective ones discarded.

In the early days, these filaments were made of cardboard or bamboo, and later, of thread treated with sulphuric acid.

A few of the shapes of filaments now in use are shown in Fig. 1, the different shapes giving a slightly different distribution of light. As here shown they are designated as follows: A, U-shaped; B, single-curl; C, single-curl anchored; D, double-loop; E, double-curl; F, double-curl anchored.

Mounting the Filament. After carbonization, the filaments are mounted or joined to wires leading into the globe or bulb. These wires are made of platinum—platinum being the only substance, so far as known, that expands and contracts the same as glass, with change in temperature and which, at the same time, will not be melted by the heat developed in the carbon. Since the bulb must remain air-tight, a substance expanding at a different rate from the glass cannot be used. Several methods of fastening the filament to the *leading in* wires have been used, such as forming a socket in the end of the wire, inserting the filament, and then squeezing the socket tightly against the carbon; and the use of tiny bolts when cardboard filaments were used; but the pasted joint is now used almost exclusively. Finely powdered carbon is mixed with some adhesive compound, such as molasses, and this mixture is used as a paste for fastening the carbon to the platinum. Later, when current is sent through the joint, the volatile matter is driven off and only the carbon remains. This makes a cheap and, at the same time, a very efficient joint.

Flashing. Filaments, prepared and mounted in the manner just described, are fairly uniform in resistance, but it has been found that their quality may be much improved and their resistance very closely regulated by depositing a layer of carbon on the outside of the filament by the process of *flashing*. By flashing is meant heating the filament to a high temperature when immersed in a hydrocarbon gas, such as gasoline vapor, under partial vacuum. Current is passed through the filament in this process to accomplish the heating. Gas is used, rather than a liquid, to prevent too heavy a deposit of the carbon. Coal gas is not recommended because the carbon, when deposited from this, has a dull black appearance. The effects of flashing are as follows:

1. The diameter of the filament is increased by the deposited carbon and hence its resistance is decreased. The process must be

discontinued when the desired resistance is reached. Any little irregularities in the filament will be eliminated since the smaller sections, having the greater resistance, will become hotter than the remainder of the filament and the carbon is deposited more rapidly at these points.

2. The character of the surface is changed from a dull black and comparatively soft nature to a bright gray coating which is much harder and which increases the life and efficiency of the filament.

Exhausting. After flashing, the filament is sealed in the bulb and the air exhausted through the tube *A* in Fig. 2, which shows the lamp in different stages of its manufacture. The exhaustion is accomplished by means of mechanical air pumps, supplemented by Sprengle or mercury pumps and chemicals. Since the degree of exhaustion must be high, the bulb should be heated during the process so as to drive off any gas which may cling to the glass. When chemicals are used, as is now almost universally the case, the chemical is placed in the tube *A* and, when heated, serves to take up much of the remaining gas. Exhaustion is necessary for several reasons:

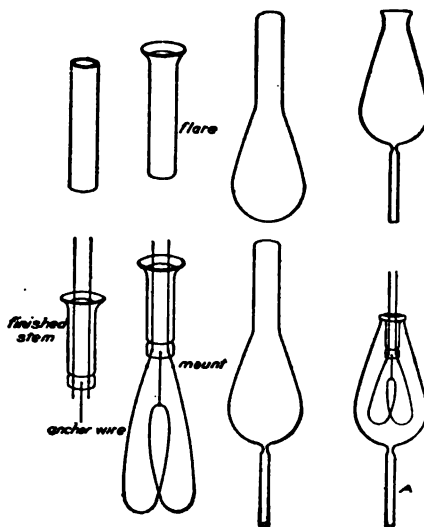


Fig. 2. Different Stages in Lamp Manufacture.

1. To avoid oxidization of the filament.
2. To reduce the heat conveyed to the globe.
3. To prevent wear on the filament due to currents or eddies in the gas.

After exhausting, the tube *A* is sealed off and the lamp completed for testing by attaching the base by means of plaster of Paris. Fig. 3 shows some of the forms of completed incandescent lamps.

Voltage and Candle-Power. Incandescent lamps of the carbon type vary in size from the miniature battery and candelabra lamps to those of several hundred candle-power, though the latter are very seldom used. The more common values for the candle-power are

8, 16, 25, 32, and 50, the choice of candle-power depending on the use to be made of the lamp.

The voltage will vary depending on the method of distribution of the power. For what is known as *parallel distribution*, 110 or 220 volts are generally used. For the higher values of the voltage, long and slender filaments must be used, if the candle-power is to be low; and lamps of less than 16 candle-power for 220-volt circuits are not practical, owing to difficulty in manufacture. For series distribution, a low voltage and higher current is used, hence the filaments may be quite heavy. Battery lamps operate on from 4 to 24 volts, but the vast majority of lamps for general illumination are operated at or about 110 volts.

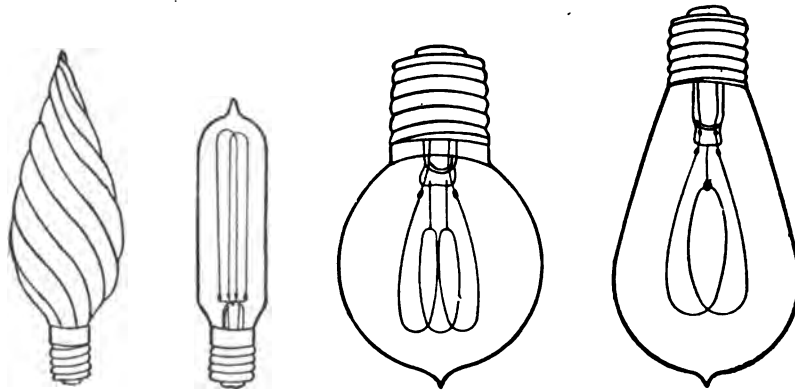


Fig. 3. Several Forms of Completed Lamps.

Efficiency. By the efficiency of an incandescent lamp is meant the power required at the lamp terminals per candle-power of light given. Thus, if a lamp giving an average horizontal candle-power of 16 consumes $\frac{1}{2}$ an ampere at 112 volts, the total number of watts consumed will be $112 \times \frac{1}{2} = 56$, and the watts per candle-power will be $56 \div 16 = 3.5$. The efficiency of such a lamp is said to be 3.5 watts per candle-power, or simply watts per candle. *Watts economy* is sometimes used for *efficiency*.

The efficiency of a lamp depends on the temperature at which the filament is run. In the ordinary lamp this temperature is between $1,280^{\circ}$ and $1,330^{\circ}$ C, and the curve in Fig. 4 shows the increase of efficiency with the increase of temperature. The temperature attained

by a filament depends on the rate at which heat is radiated and the amount of power supplied. The rate of radiation of heat is proportional to the area of the filament, the elevation in temperature, and the emissivity of the surface.

By emissivity is meant the number of heat units emitted from unit surface per degree rise in temperature above that of surrounding bodies. The bright surface of a flashed filament has a lower emissivity than the dull surface of an unheated filament, hence less energy is lost in heat radiation and the efficiency of the filament is increased.

As soon as incandescence is reached, the illumination increases much more rapidly than the emission of heat, hence the increase in

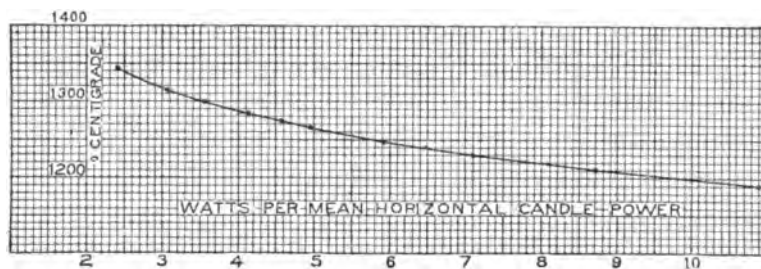


Fig. 4. Efficiency Curve for Incandescent Lamp.

efficiency shown in Fig. 4. Were it not for the rapid disintegration of the carbon at high temperature, an efficiency higher than 3.1 watts could be obtained.

By a special treatment of the carbon filaments, the nature of the carbon is so changed that the filaments may be run at a higher temperature and the lamps still have a life comparable to that of the 3.1-watt lamp. Lamps using these special carbon filaments are known as *gem metallized filament lamps*, or merely as *gem lamps*, and they will be described more fully later.

Relation of Life to Efficiency. Ordinary Carbon Lamp. By the useful life of a lamp is meant the length of time a lamp will burn before its candle-power has decreased to such a value that it would be more economical to replace the lamp with a new one than to continue to use it at its decreased value. A decrease to 80% of the initial candle-power of carbon lamps is now taken as the point at which a lamp should be replaced, and the normal life of a lamp is in the

neighborhood of 800 hours. To obtain the most economical results, such lamps should always be replaced at the end of their useful life.

In Table I are given values of efficiency and life of a 3.5-watt, 110-volt carbon lamp for various voltages impressed on the lamp. These values are plotted in Fig. 5. The curves show that a 3% increase of voltage on the lamp reduces the life by one-half, while an increase of 6% causes the useful life to fall to one-third its normal value. The effect is even greater when 3.1-watt lamps are used, but not so great with 4-watt lamps. From this we see that the regulation of the voltage used on the system must be very good if high efficiency lamps are to be used, and this regulation will determine the efficiency of the lamp to be installed.

Selection of Lamps. *Ordinary Carbon Type.* Lamps taking 3.1 watts per candle-power will give satisfaction only when the regulation of voltage is the best—practically a constant voltage maintained at the normal voltage of the lamp.

TABLE I
Effects of Change in Voltage
Standard 3.5-Watt Lamp

VOLTAGE PER CENT. OF NORMAL	CANDLE-POWER PER CENT. OF NORMAL	WATTS PER CANDLE-POWER	LIFE PER CENT. OF NORMAL	DETERIORATION PER CENT. OF NORMAL
90	53	5.36		
91	56	5.09		
92	61	4.85		
93	65	4.63		
94	69	4.44	394	25
95	73	4.26	310	32
96	78	4.09	247	44
97	83	3.93	195	51
98	88	3.78	153	65
99	94	3.64	126	79
100	100	3.5	100	100
101	106	3.38	84	118
102	111	3.27	68	146
103	116	3.16	58	173
104	123	3.05	47	211
105	129	2.95	39	253
106	137	2.85	31	316
107	143	2.76	26	380
108	152	2.68	21	474
109	159	2.60	17	575
110	167	2.53	16	637

Lamps of 3.5 watts per candle-power should be used when the regulation is fair, say with a maximum variation of 2% from the normal voltage.

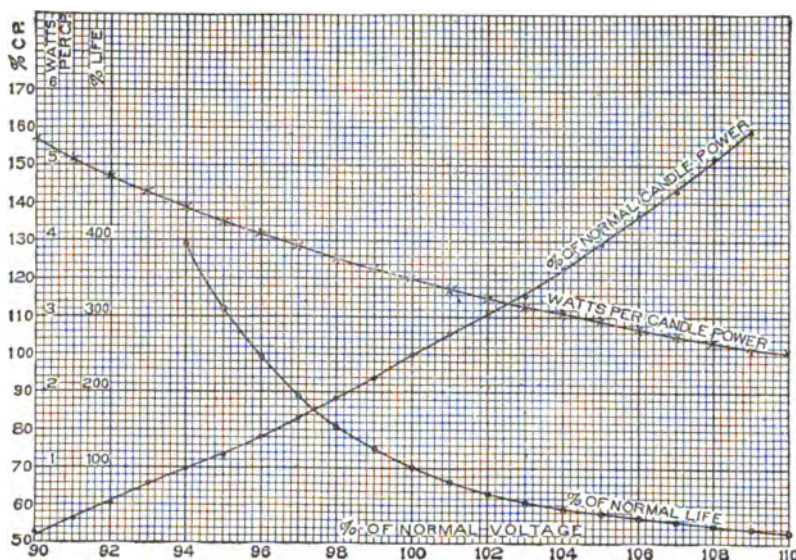


Fig. 5. Curves of Efficiency and Life of Carbon Filament Lamps.

Lamps of 4 watts per candle-power should be installed when the regulation is poor. These values are for 110-volt lamps. A 220-volt lamp should have a lower efficiency to give a long life. This is on

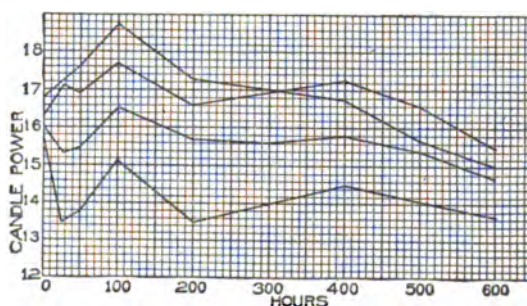


Fig. 6. Life Curves of Incandescent Lamps.

account of the fact that, for the same candle-power, the 220-volt lamp must be constructed with a filament which is long and slender compared to that of the 110-volt lamp, and if such a filament is run at a high temperature its life is short. The 220-volt lamp is used to some considerable extent abroad but it is not employed extensively in the United States. It is customary to operate such lamps at an efficiency of about 4 watts per candle-power.

Lamps should always be renewed at the end of their useful life, this point being termed the *smashing-point*, as it is cheaper to replace the lamp than to run it at the reduced candle-power. Some recommend running these lamps at a higher voltage, but that means at a reduced life, and it is not good practice to do this.

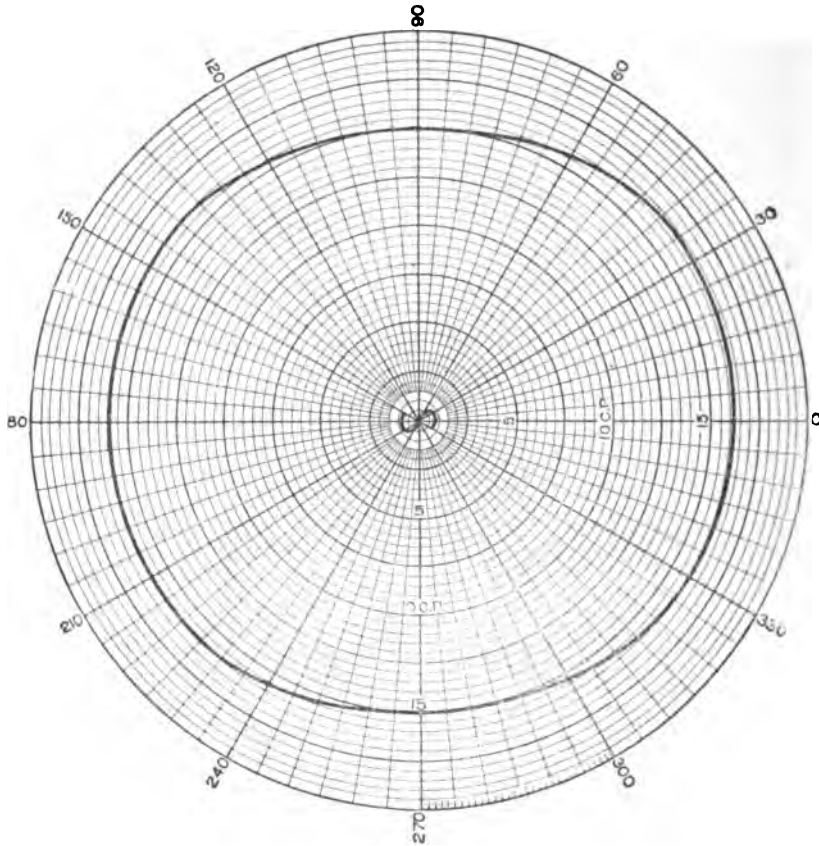


Fig. 7. Horizontal Distribution Curve for Single-Loop Filament.

Fig. 6 shows the life curves of a series of incandescent lamps. These curves show that there is an increase in the candle-power of some of the lamps during the first 100 hours, followed by a period during which the value is fairly constant, after which the light given by the lamp is gradually reduced to about 80% of the initial candle-power.

Distribution of Light. In Fig. 1 are shown various forms of filaments used in incandescent lamps, and Figs. 7 and 8 show the distribution of light from a single-loop filament of cylindrical cross-section. Fig. 7 shows the distribution of light in a horizontal plane, the lamp being mounted in a vertical position, and Fig. 8 shows the dis-

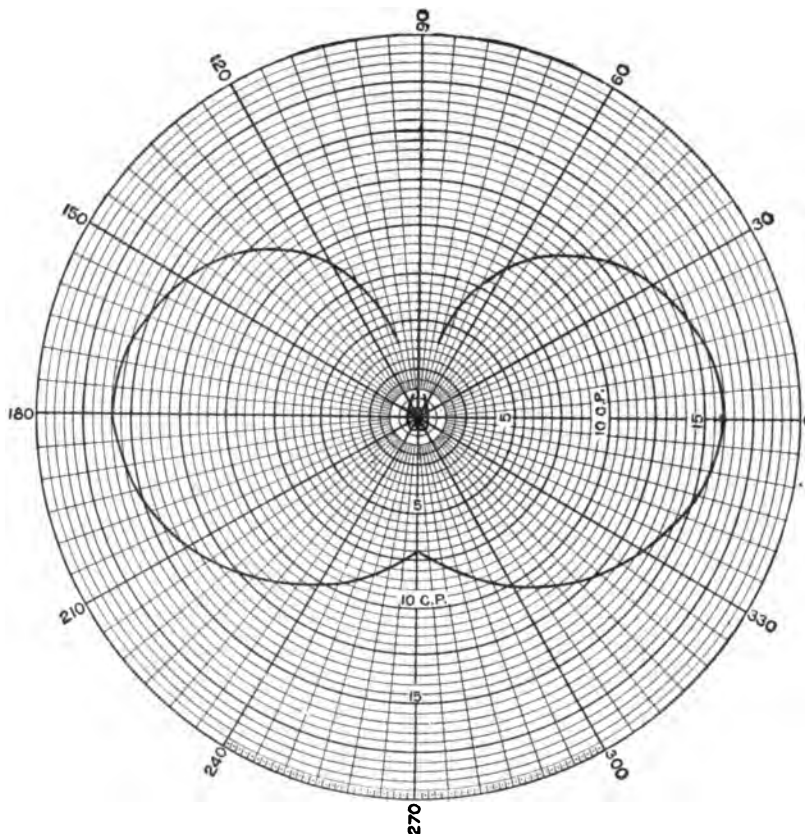


Fig. 8. Vertical Distribution Curve for Single-Loop Filament.

tribution in a vertical plane. By changing the shape of the filament, the light distribution is varied. A mean of the readings taken in the horizontal plane forms the *mean horizontal candle-power*, and this candle-power rating is the one generally assumed for the ordinary incandescent lamp. A mean of the readings taken in a vertical plane gives us the mean vertical candle-power, but this value is of little use.

Mean Spherical Candle-Power. When comparing lamps which give an entirely different light distribution, the mean horizontal candle-power does not form a proper basis for such comparison, and the mean spherical or the mean hemispherical candle-power is used instead. By *mean spherical candle-power* is meant a mean value of the light taken in all directions. The methods for determining this will be taken up under *photometry*. The mean hemispherical candle-power has reference, usually, to the light given out below the horizontal plane.

The Gem Metallized Filament Lamp. When the incandescent lamp was first well established commercially, the useful life of a unit, when operated at 3.1 watts per candle, was about 200 hours. The improvements in the process of manufacture have been continuous from that time until now, and the useful life of a lamp operated at that efficiency to-day is in the neighborhood of 500 hours. Experiments in the treatment of the carbon filament have led to the introduction of the *gem metallized filament lamp*. This lamp should not be confused with the metallic filament lamps, to be described later, because the material used is carbon, not a metal. As a result of special treatment the carbon filament assumes many of the characteristics of a metallic conductor, hence the term *metallized filament*. The word *graphitized* has been proposed in place of metallized.

TABLE II
* Data on the Gem Metallized Filament Lamp

WATTS	HORIZONTAL C. P.	WATTS PER CANDLE	† SPHERICAL REDUCTION FACTOR	§ USEFUL LIFE
40	16	2.5	.816	450 hrs.
50	20	2.5	.825	450 "
80	32	2.5	.816	450 "
100	40	2.5	†	460 "
125	50	2.5	†	450 "
187.5	75	2.5	†	450 "
250	100	2.5	†	450 "

* These lamps are normally rated at three voltages, 114, 112, and 110 volts, but data referring to the highest voltage only are given.

† By spherical reduction factor is meant the factor by which the horizontal candle-power must be multiplied to obtain the mean spherical candle-power.

‡ The larger units are almost invariably used with reflectors, hence no spherical reduction factor is given.

§ The life of the lamps when operated at the lower voltage is increased to about 950 hours, and the efficiency is changed to 2.83 watts per candle.

When a filament, as treated in the ordinary manner, is run at a high temperature in a lamp there is no improvement of the filament, but it was discovered that, if the treated filaments were subjected to the extremely high temperature of the electric resistance furnace—3,000 to 3,700 degrees C.—at atmospheric pressure, the physical nature of the carbon was changed and the resulting filament could be operated at a higher temperature in the lamp and a higher efficiency,

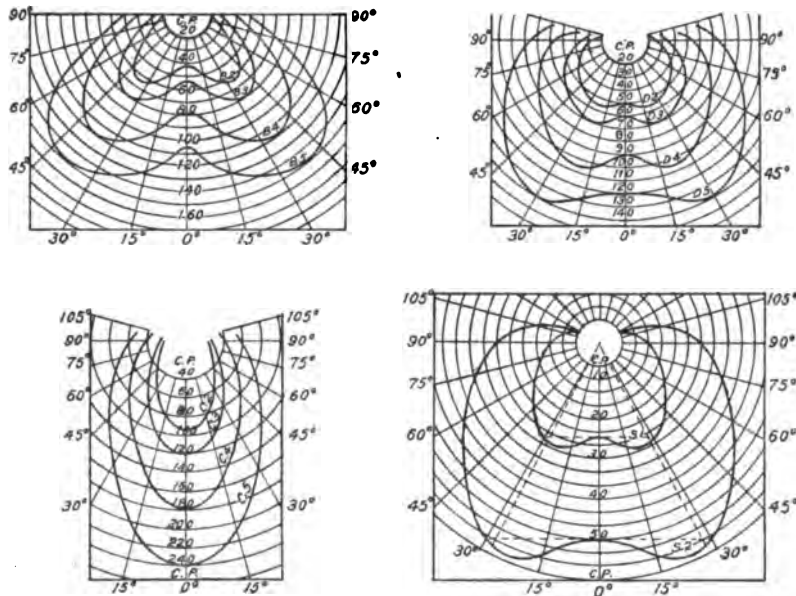


Fig. 9. Typical Distribution Curves of Gem Lamp with Different Types of Reflectors.

and still maintain a life comparable to that of a 3.1-watt lamp. This special heating of the filament, which is applied to the base filament before it is flashed, as well as to the treated filament, causes the cold resistance of the carbon to be very materially decreased and the filament, as used in the lamp, has a positive temperature coefficient—rise in resistance with rise in temperature—a desirable feature from the standpoint of voltage regulation of the circuit from which the lamps are operated. The high temperature also results in the driving off of considerable of the material which, in the ordinary lamp, causes the globe to blacken after the lamp has been in use for some time. The blackening of the bulb is responsible to a considerable degree

for the decrease in candle-power of the incandescent lamp. The metallized filament lamp is operated at an efficiency of 2.5 watts per candle with a useful life of about 500 hours. The change in candle-power with change in voltage is less than in the ordinary lamp on account of the positive temperature coefficient of the filament. These lamps are not manufactured for very low candle-powers, owing to the



Fig. 10. Round Bulb Tantalum Lamp.

difficulty of treating very slender filaments, but they are made in sizes consuming from 40 to 250 watts. Table II gives some useful information in connection with metallic filament lamps. The filaments are made in a variety of shapes and the distribution curves are usually modified in practice by the use of shades and reflectors. The general appearance of the lamp does not differ from that of the ordinary carbon lamp. Fig. 9 shows typical distribution curves of the metallized filament lamp as it is installed in practice.

Metallic Filament Lamps. *The Tantalum Lamp.*

The first of the metallic filament lamps to be introduced to any considerable extent commercially was the tantalum lamp. Dr. Bolton of the Siemens & Halske Company first discovered the methods of obtaining the pure metal tantalum. This metal is rendered ductile and drawn into slender filaments for incandescent lamps. Tantalum has a high tensile strength and high melting point, and tantalum filaments are operated at temperatures much higher than those used with the carbon filament lamp. On account of the comparatively low specific resistance of this material the filaments for 110-volt lamps must be long and slender, and this necessitates a special form of support. Figs. 10, 11, and 12 show some interesting views of the tantalum lamp and the filament. This lamp is operated at the efficiency of 2 watts per



Fig. 11. Tantalum Filament Before and After 1,000 Hours' Use.

candle-power, with a life comparable to that of the ordinary lamp. By special treatment it is possible to increase the resistance of the filaments so that they may be shorter and heavier than those used in

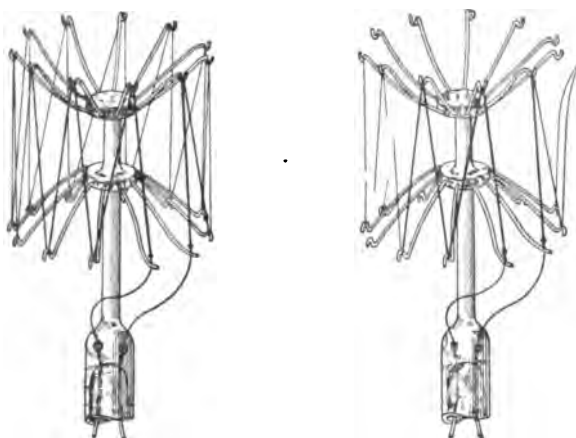


Fig. 12.

Appearance of Filament After
Having Been Used.

Filament Frame Showing
Broken Filament.

the first of the tantalum lamps. It should be noted that the life of this type of lamp on alternating-current circuits is somewhat uncertain; it is much more satisfactory for operation on direct-current circuits. Tables III and IV give some general data on the tantalum lamp, and Figs. 13 and 14 show typical distribution curves for the units as installed at present.

TABLE III

Data on Tantalum Lamp

GENERAL ELECTRIC CO., MFTRs.

SIZE OF BULB		DIAMETER OF BULB IN INCHES	ESTIMATED LIFE	
REGULAR	ROUND		ON A. C.	ON D. C.
40 watt		$2\frac{5}{8}$	350	800
50 "		$2\frac{5}{8}$	350	800
80 "		$3\frac{1}{8}$	400	800
		$3\frac{3}{4}$	350	800
		5	400	800
	40 watt			
	80 "			

TABLE IV
Data on the Life of a 25-C. P. Unit

NO. OF HOURS BURNED	CANDLE-POWER	WATTS PER CANDLE
0	19.8	2.17
25	23.6	1.865
50	23.1	1.90
125	22.3	1.98
225	22.4	1.96
350	22.3	1.97
450	22.2	1.98
550	21.2	2.05
650	19.6	2.20

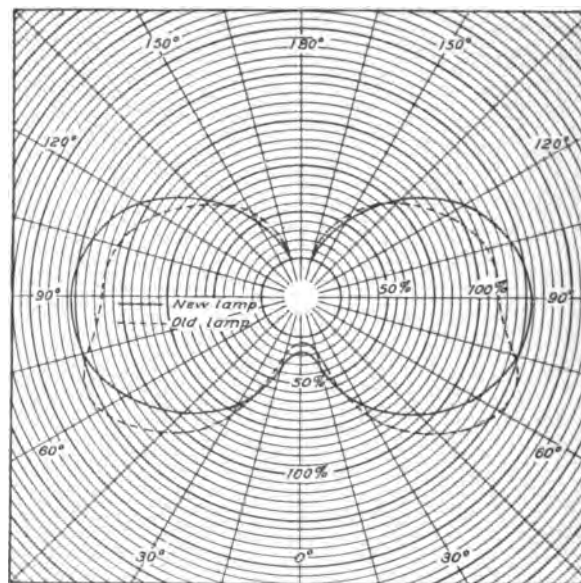


Fig. 13. Vertical Distribution Curve Without Reflector.

The Tungsten Lamp. Following closely upon the development of the tantalum lamp came the tungsten lamp. Tungsten possesses a very high melting point and an indirect method is employed in forming filaments for incandescent lamps. There are several of these methods in use. In one method a fine carbon filament is flashed in an atmosphere of tungsten oxychloride mixed with just the proper proportion of hydrogen, in which case the filament gradually changes

to one of tungsten. A second method consists of the use of powdered tungsten and some binding material, sometimes organic and in other cases metallic. The powdered tungsten is mixed with the binding material, the paste squirted into filaments, and the binding material is then expelled, usually by the aid of heat. Another method of manufacture consists of securing tungsten in colloidal form, squirting it

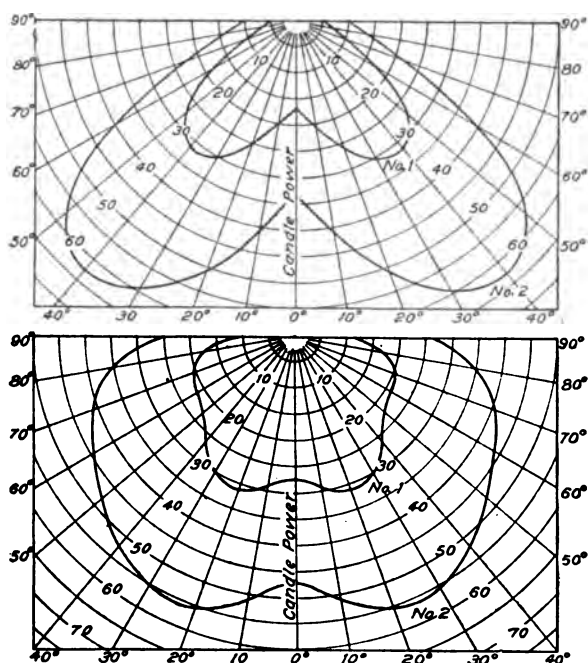


Fig. 14. Distribution Curves for Tantalum Lamp. No. 1, 40 Watts; No. 2, 80 Watts.

into filaments, and then changing them to the metallic form by passing electric current through the filaments.

The tungsten lamp has the highest efficiency of any of the commercial forms of metallic filament lamps now in use, about 1.25 watts per candle-power when operated so as to give a normal life, and lamps for 110-volt service and consuming but 40 watts have recently been put on the market. A 25-watt lamp for this same voltage appears to be a possibility. The units introduced at first were of high candle-power because of the difficulty of manufacturing the slender filaments required for the low candle-power lamps.

The advantages of these metals, tantalum and tungsten, for incandescent lamps are in the improved efficiency of the lamps and the good quality of the light, white or nearly white in both cases. In either case the change in candle-power with change in voltage is less than the corresponding change in an ordinary carbon lamp. The disadvantage lies in the fact that the filaments must be made long and slender, and hence are fragile, for low candle-power units to be used

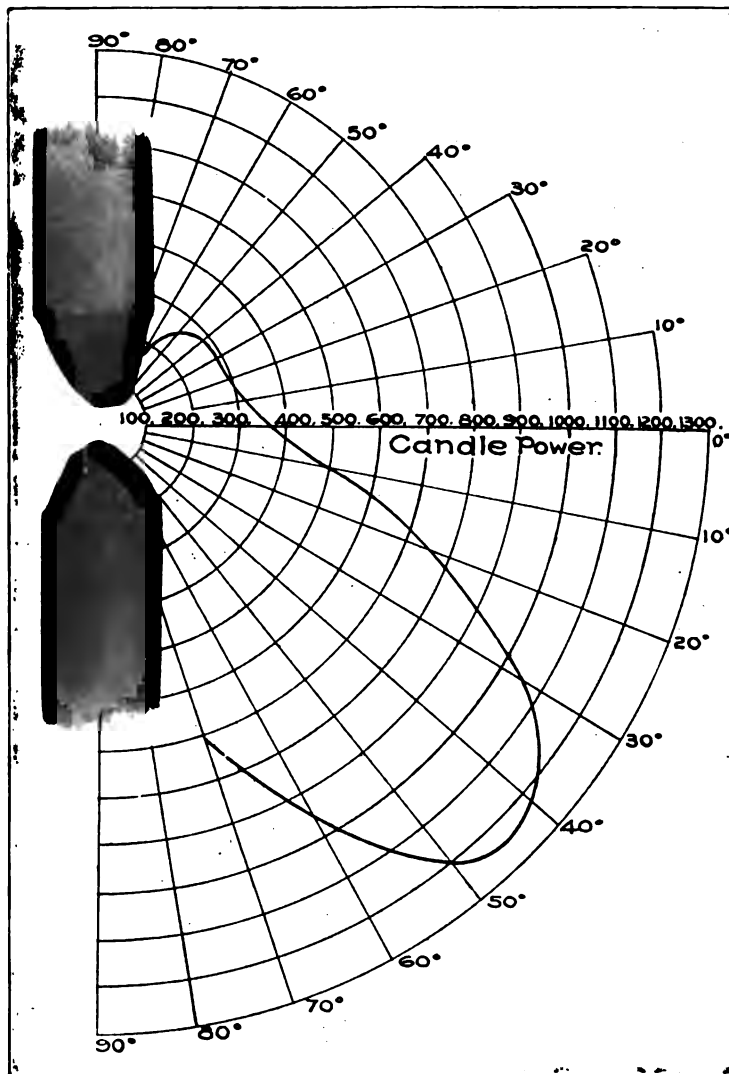


Fig. 15. Multiple Tungsten Lamp.



Fig. 16. Series Tungsten Lamp.

on commercial voltages. In some cases tungsten lamps are constructed for lower voltages and are used on commercial circuits through the agency of small step-down transformers. Improvements in the process of manufacture of filaments and of the method of their support have resulted in the construction of 110-volt lamps for candle-powers lower than was once thought possible. Figs. 15 and 16 show the appearance of the tungsten lamp, and Figs. 17 and 18 give some



DISTRIBUTION CURVE FOR ARC LAMP.

Fort Wayne Electric Works.

typical distribution curves. Tables V and VI give data on this lamp as it is manufactured at present. One very considerable application

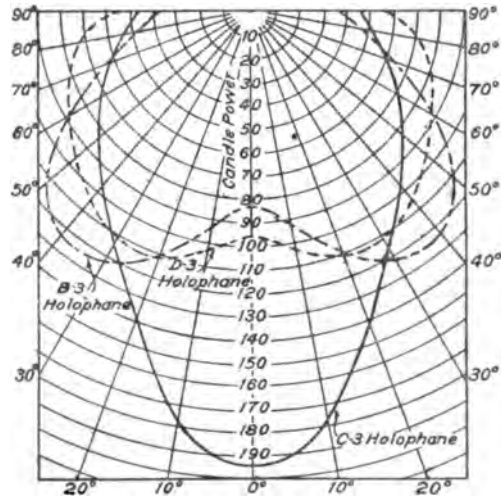


Fig. 17. C. P. Distribution Curves of 100-Watt Gen. Elec. Tungsten Incandescent Units with B-3, C-3, and D-3 Holophanes.

of the tungsten lamp is to incandescent street lighting on series circuits, in which case the lamp may be made for a low voltage across its terminals and the filament may be made comparatively short and

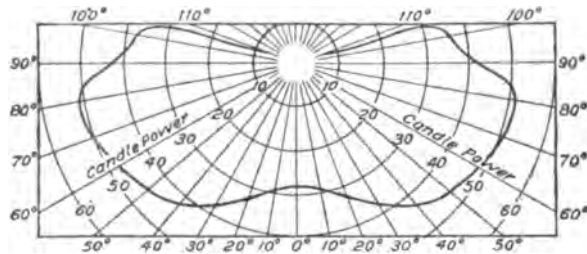


Fig. 18. Candle-Power Distribution Given with 40 c. p. Gen. Elec. Tungsten Series Lamp and Radial Wave Reflector.

heavy. The tungsten lamp is also being introduced as a low voltage battery lamp.

The Just lamp, the Z lamp, the Osram lamp, the Zircon-Wolfram lamp, the Osmin lamp, etc., are all tungsten lamps, the filaments being prepared by some of the general methods already described or modifications of them.

TABLE V
Tungsten Lamps
MULTIPLE

WATTS	VOLTS	CANDLE-POWER	WATTS PER C. P.	TIP CANDLE-POWER	SPHERICAL REDUCTION FACTOR
40	100	32	1.25	5	76.3
60	125	40	1.25	5.6	76.3

TABLE VI
Tungsten Lamps
SERIES

AMPERES	VOLTS	CANDLE-POWER	WATTS PER C. P.
4	13.5	40	1.35
	20.25	60	
5.5	9.8	40	1.35
	14.7	60	
6.6	8.2	40	1.35
	12.3	60	
7.5	7.2	40	1.35
	10.8	60	

The Osmium Lamp. Very efficient incandescent lamps have been constructed using osmium for the filament. An indirect method is resorted to in the formation of these filaments. Osmium lamps have not been successful for commercial voltages because the filament is too fragile if it is made to have a high resistance, so these lamps must be operated in series or through the agency of reducing transformers if they are to be applied to 110-volt circuits. At 25 volts, lamps are constructed giving an efficiency of about 1.5 watts per candle-power with a life comparable to that of a 3.5-watt carbon lamp. Owing to the introduction of the tungsten lamp, the osmium lamp will probably never be used to any great extent.

Other Metallic Filament Lamps. Table VII gives the melting points of several metals which are highly refractory and those already mentioned are not the only ones which have been successfully used in incandescent lamps. Titanium, zirconium, iridium, etc., have been successfully employed, but the tantalum and tungsten lamps are the only ones which are used to any extent in the United States.

TABLE VII
Melting Point of Some Metals

METAL	APPROXIMATE MELTING POINT IN DEGREES C.
Tungsten	3080-3200
Titanium	3000
Tantalum	2900
Osmium	2500
Platinum	1775
Zirconium	1500
Silicon	1200
Carbon (not a metal)	3000

The Helion Lamp. The helion lamp, which gives considerable promise of commercial development, is a compromise between the carbon lamp and the metallic filament lamp. A slender filament of carbon is flashed in a compound of silicon (gaseous state) and a filament composed of a carbon core more or less impregnated with silicon and coated with a metallic layer is formed. The emissivity of such a filament is high, the light is white in color, and the filament is strong. The efficiency of the helion filament as far as it has been developed is higher than that of a carbon filament when operated at the same temperature. At 1,500 degrees C. the efficiency of the helion filament is 2.15 watts per candle-power, while for a carbon filament it is about 3.5 watts per candle-power. Filaments of this type have been made which may be heated to incandescence in open air without immediate destruction. This lamp is not yet on the market.

The Nernst Lamp. The Nernst lamp is still another form of incandescent lamp, several types of which are shown in Figs. 19, 20, 21, and 22. This lamp uses for the incandescent material certain oxides of the rare earths, the oxides being mixed in the form of a paste, then squirted through a die into a string which is subjected to a roast-



Fig. 19. Westinghouse Nernst
Multiple-Glow Lamp.

ing process forming the filament or *glower* material of the lamp as represented by the lower white line in Fig. 23. The more recent glowers are made hollow instead of solid. The glowers are cut to

the desired length and platinum terminals attached. The attachment of these terminals to the glowers is an important process in the manufacture of the lamp. The recent discovery of additional oxides has led to the construction of glowers which show a considerable gain in efficiency over those previously used. The glowers are heated to incandescence in open air, a vacuum not being required.

As the glower is a non-conductor when cold, some form of *heater* is necessary to bring it up to a temperature at which it will conduct. Two forms of heater have been used. One of them consists of a porcelain tube shown just above the glower, Fig. 23, about which a fine platinum wire is wound; the wire is in turn coated with a cement. Two or more of these tubes are mounted directly over the glower, or glowers, and serve as a reflector as well as a heater. The second form of heater consists of a slender rod of refractory material about which a platinum wire is wound, the wire again being covered with

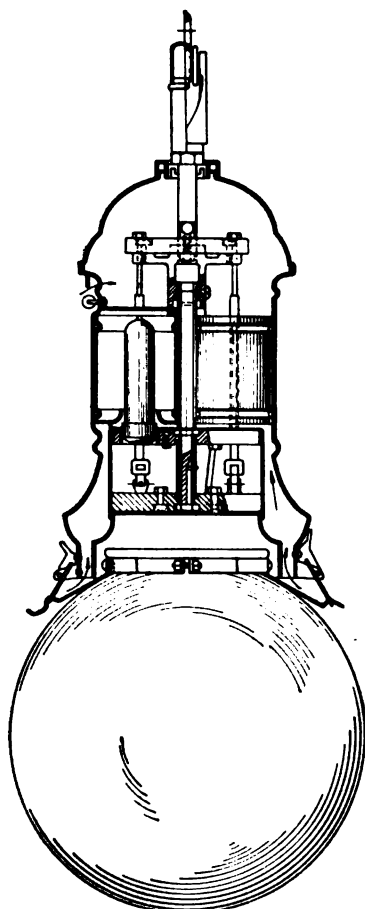


Fig. 20. Sectional View of Multiple-Glower Westinghouse Nernst Lamp.

a cement. This rod is then formed into a spiral which surrounds the glower in the vertical glower type, or is formed into the *wafer heater*, Fig. 24, now universally employed in the Westinghouse Nernst lamp with horizontal glowers. The wafer heater is bent so that it can be mounted with several sections parallel to the glower or glowers.

The heating device is connected across the circuit when the lamp is first turned on, and it must be cut out of circuit after the glowers become conductors in order to save the energy consumed by the

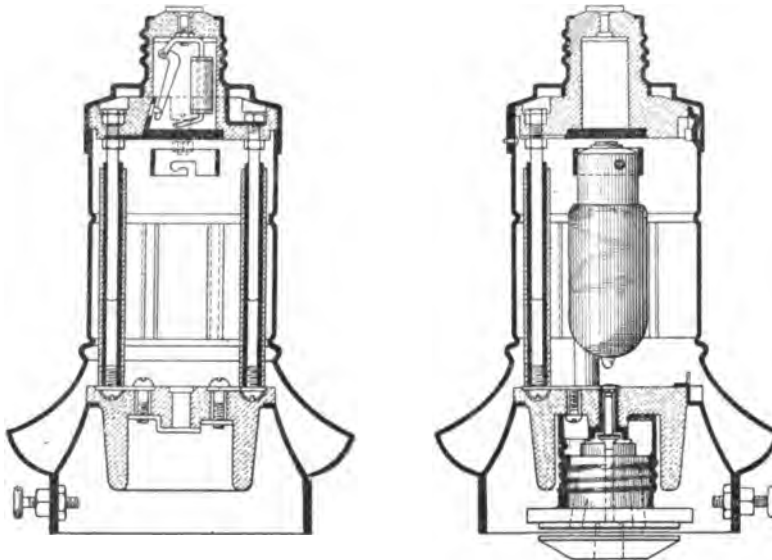


Fig. 21. Sectional Views of Single-Glower Westinghouse Nernst Lamp.

heater and to prolong the life of the heater. The automatic *cut-out* is operated by means of an electromagnet so arranged that current flows through this magnet as soon as the glower becomes a conductor, and contacts in the heater circuit are opened by this magnet. The contacts in the heater circuit are kept normally closed, usually by the force of gravity.

The conductivity of the glower increases with the increase of temperature—the material has a negative temperature coefficient—hence if it were used on a constant potential circuit directly, the current and temperature would continue to rise until the glower was destroyed. To prevent the current



Fig. 22. Westinghouse Nernst Screw Burner.

from increasing beyond the desired value, a *ballast resistance* is used in series with the glower. As is well known, the resistance of iron wire increases quite rapidly with increase in temperature, and



Fig. 23. Westinghouse Nernst Screw Burner with Globe Removed, Showing Glower and Tubular Heater.

the resistance of a fine pure iron wire is so adjusted that the resistance of the combined circuit of the glower and the ballast becomes constant at the desired temperature of the glower. The iron wire must be protected from the air to prevent oxidization and too rapid temperature changes, and, for this reason, it is mounted in a glass bulb filled with hydrogen. Hydrogen has been selected for this purpose because it is an inert gas and conducts the heat from the ballast to the walls of the bulb better than other gases which might be used.

All of the parts enumerated, namely, glower, heater, cut-out, and ballast, are mounted in a suitable manner; the smaller lamps have but one glower and are arranged to fit in an incandescent lamp socket, while the larger types are constructed at present with four glowers

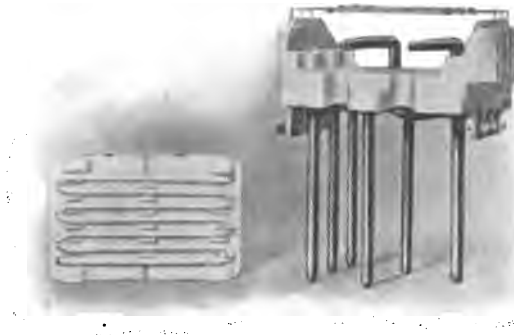


Fig. 24. Wafer Heater and Mounting.

and are arranged to be supported in special fixtures, or the same as small arc lamps. All parts are mechanically arranged so that renewals may be easily made when necessary and it is not possible to insert a part belonging to one type of lamp into a lamp of a different type.

The advantages claimed for the Nernst lamp are: High efficiency; a good color of light; a good distribution of light without the use of reflectors; a long life with low cost of maintenance; and a complete series of sizes of units, thus allowing its adaption to practically all classes of illumination.

The lamp is constructed for both direct- and alternating-current service and for 110 and 220 volts. When the alternating-current lamp is used on a 110-volt circuit a small transformer, commonly called a *converter coil*, Fig. 25, is utilized to raise the voltage at the lamp terminals to about 220 volts.



Fig. 25. Converter Coil.

Data on the Nernst lamp in its present form are given in Table VIII, and Figs. 26 and 27 show the form of distribution curves.

TABLE VIII
General Data on the Nernst Lamp

LAMP RATING IN WATTS	VOLTAGE	CURRENT IN AMPERES	MAX. CANDLE- POWER	MEAN HEMISPHER- ICAL C. P.	WATTS PER M. H. S. C. P. FROM TEST	
66	110	.6	74	50	1.38	
88	220	.4	105	77	1.2	} 1-Glower A.C. or D.C.
110	110	1.0	131	96.4	1.2	
	220	.5				
132	110	1.2	156	114	1.2	
	220	.6				
264	220	1.2	345	231	1.2	} 2-Glower A.C. or D.C.
396	220	1.8	528	359	1.15	
528	220	2.4	745	504	1.09	

Comparison of the Different Types of Incandescent Lamps. A direct comparison of the different types of incandescent lamps cannot be made but it is desirable at this time to note the following points: The lamps which are considered commercial in the United States at the present time are the carbon, gem, tantalum, tungsten, and Nernst lamp. The efficiencies ordinarily accepted run in the order

given, approximately 3.1, 2.5, 2, 1.25, and 1.2 watts per candle respectively. The figure of 1.2 watts per candle for the Nernst lamp is based upon the mean hemispherical candle-power and it should not be compared directly with the other efficiencies. The color of the light in all of the above cases is suitable for the majority of classes of illumination, the light from the higher efficiency units being somewhat whiter than that from the carbon lamp. All of these lamps are constructed for commercial voltages and for either direct or alternating current. The use of the tantalum lamp on alternating current is not

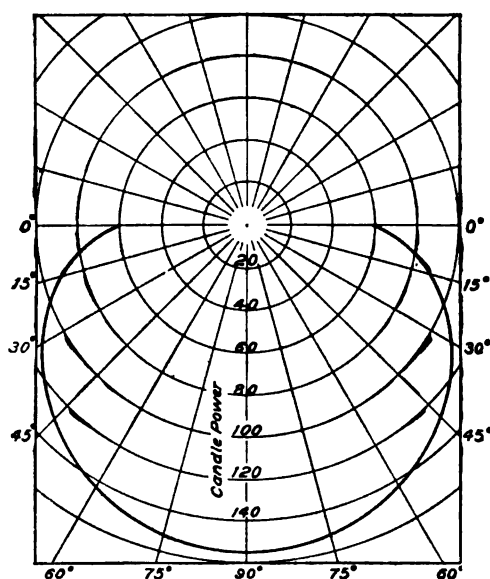


Fig. 26. Distribution Curve of 132-Watt Type Westinghouse Nernst Lamp. Single Glower.

always to be recommended as the service is unsatisfactory in some cases. The minimum size of units for 110 volts is about 4 candle-power for the carbon lamp, 20 candle-power for the metallic filament lamp, and 50 candle-power (mean hemispherical) for the Nernst lamp. Some of the metallic filament lamps are constructed for a consumption of as high as 250 watts, while the largest size of the Nernst lamp uses 528 watts. The light distribution of any of the units is subject to considerable variation through the agency of reflectors, but the Nernst lamp is ordinarily installed without a reflec-

tor. Practically all of the other units of high candle-power use reflectors and only a few of the typical curves of light distribution curves with reflectors have been shown in connection with the description of the lamps. The life of all of the commercial lamps described is considered as satisfactory. The minimum life is seldom less than 500 hours and the useful life is generally between 500 and 1,000 hours. On account of the slender filaments employed in the metallic filament

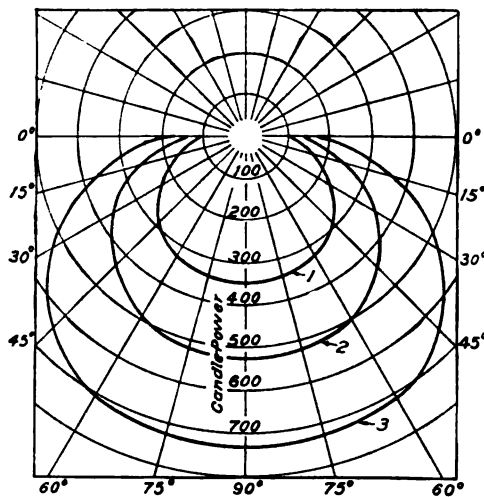


Fig. 27. Distribution of Light from Multiple-Glow Westinghouse Nernst Lamps with 8" Clear Globes. No. 1, 2 Glow; No. 2, 3 Glow; No. 3, 4 Glow.

lamps they are not made for low candle-powers at commercial voltages. The introduction of transformers for the purpose of changing the circuit voltage to one suitable for low candle-power units has not become at all general as yet in this country.

SPECIAL LAMPS

The Mercury Vapor Lamp. The mercury vapor lamp in this country is put on the market by the Cooper-Hewitt Electric Company and it is being used to a considerable extent for industrial illumination. In this lamp mercury vapor, rendered incandescent by the passage of an electric current through it, is the source of light. In its standard form this lamp consists of a long glass tube from which the air has been carefully exhausted, and which contains a small amount of metallic mercury. The mercury is held in a large bulb at one end of

the tube and forms the negative electrode in the direct-current lamp. The other electrode is formed by an iron cup and the connections between the lamp terminals and the electrodes are of platinum where this connection passes through the glass. Fig. 28 gives the general appearance of a standard lamp having the following specifications:

Total watts (110 volts, 3.5 amperes) = 385

Candle-power (M. H. with reflector) = 700

Watts per candle = 0.55

Length of tube, total = 55 in.

Length of light-giving section = 45 in.

Diameter of tube = 1 in.

Height from lowest point of lamp to ceiling plate = 22 in.

For 220-volt service two lamps are connected in series.

The mercury vapor, at the start, may be formed in two ways: First, the lamp may be tipped so that a stream of mercury makes



Fig. 28. Cooper-Hewitt Mercury Vapor Lamp.

contact between the two electrodes and mercury is vaporized when the stream breaks. Second, by means of a high inductance and a quick break switch, a very high voltage sufficient to pass a current from one electrode to the other through the vacuum, is induced and the conducting vapor

is formed. The tilting method of starting is preferred and this tilting is brought about automatically in the more recent types of lamp. Fig. 29 shows the connections for automatically starting two lamps in series. A steadying resistance and reactance are connected as shown in this figure.

The mercury vapor lamp is constructed in rather large units, the 55-volt, 3.5-ampere lamp being the smallest standard size. The color of the light emitted is objectionable for some purposes as there is an entire absence of red rays and the light is practically *monochromatic*. The illumination from this type of lamp is excellent where sharp contrast or minute detail is to be brought out, and this fact has led to its introduction for such classes of lighting as silk mills and cotton mills. On account of its color the application of this lamp is limited to the lighting of shops, offices, and drafting rooms, or to dis-

play windows where the goods shown will not be changed in appearance by the color of the light. It is used to a considerable extent in photographic work on account of the actinic properties of the light. Special reactances must be provided for a mercury arc lamp operating on single-phase, alternating-current circuits.

The Moore Tube Light. The Moore light makes use of the familiar Geissler tube discharge—discharge of electricity through a vacuum tube—as a source of illumination. The practical application of this discharge to a system of lighting has involved a large amount

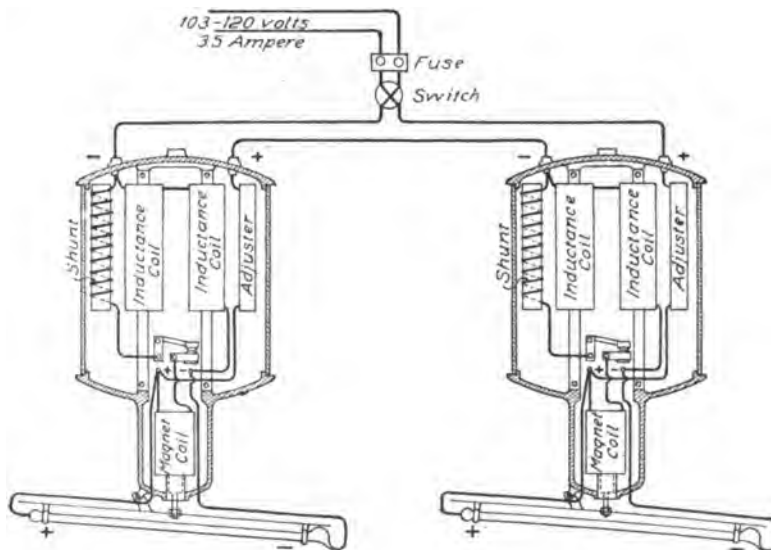


Fig. 29. Wiring Diagram. Two H Automatic Lamps in Series.

of consistent research on the part of the inventor and it has now been brought to such a stage that several installations have been made. The system has many interesting features.

In the normal method of installation, a glass tube $1\frac{3}{4}$ inches in diameter is made up by connecting standard lengths of glass tubing together until the total desired length is reached, and this continuous tube, which forms the source of light when in operation, is mounted in the desired position with respect to the plane of illumination. In many cases the tube forms a large rectangle mounted just beneath the ceiling of the room to be lighted. The tube may be of any reasonable length, actual values running from 40 to 220 feet. In order to

provide an electrical discharge through this tube it is customary to lead both ends of the tube to the high tension terminals of a transformer, the low tension side of which may be connected to the alternating-current lighting mains. This transformer is constructed so that the high tension terminals are not exposed and the current is led into the tube by means of platinum wires attached to carbon electrodes. The electrodes are about eight inches in length. The ends of the tube and the high tension terminals are enclosed in a steel casing so as to effectually prevent anything from coming in contact with the high potential of the system. As stated, the low tension side

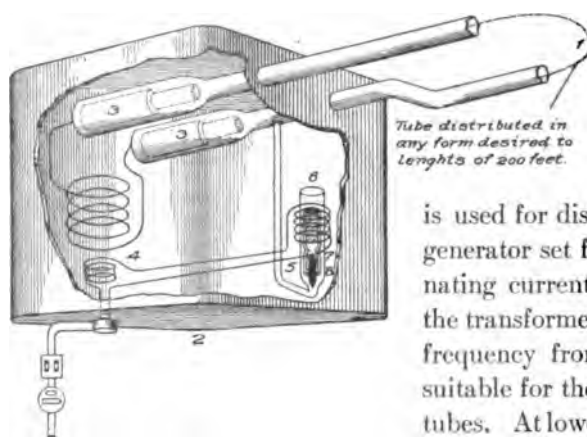


Fig. 30. Diagram Showing Essential Features of the Moore Light. 1. Lighting Tube; 2. Transformer Case; 3. Lamp Terminals; 4. Transformer; 5, 6, 7, 8, Regulators.

of the transformer is connected to the usual 60-cycle lighting mains.

If direct current is used for distribution, a motor-generator set for furnishing alternating current to the primary of the transformer is required. Any frequency from 60 cycles up is suitable for the operation of these tubes. At lower frequencies there is some appreciable variation of the light emitted. One other device is necessary for the suitable operation of this form of light and

this is known as the *regulator*. In order to maintain a constant pressure inside the tube, and such a constant pressure is necessary for its satisfactory operation, there must be some automatic device which will allow a small amount of gas to enter the tube at intervals while it is in operation. The regulator accomplishes this purpose. Fig. 30 shows a diagram of the very simple connections of the system and gives the relative positions occupied by the transformer, tube, and regulator. Fig. 31 gives an enlarged view of the regulator, a description of which and its method of operation is given as follows:

A piece of $\frac{1}{4}$ -inch glass tubing is supported vertically and its bottom end is contracted into a $\frac{3}{8}$ -inch glass tube which extends to the main lighting tube.

At the point of contraction at the bottom of the $\frac{1}{4}$ -inch tube there is sealed by means of cement a $\frac{1}{4}$ -inch carbon plug, the porosity of which is not great enough to allow mercury to percolate through it but which will permit gases easily to pass, due to the high vacuum of the lighting tube connected to the lower end of the plug, and approximately atmospheric pressure above it. This carbon plug is normally completely covered with what would correspond to a thimbleful of mercury which simply seals the pores of the carbon plug, and therefore has nothing whatever to do with the conducting properties of the gas in the main tube which produces the light. Partly immersed in the mercury and concentric with the carbon plug, is another smaller and movable glass tube, the upper end of which is filled with soft iron wire, which acts as the core of a small solenoid connected in series with the transformer. The action of the solenoid is to lift the concentric glass tube partly out of the mercury, the surface of which falls and thereby causes the minute tip of the conical shaped carbon plug to be slightly exposed for a second or two.

This exposure is sufficient to allow a small amount of gas to enter the tube, the current increases slightly, and the carbon plug is again sealed. The process above described takes place at intervals of about one minute when the tube is in operation.

The color of the light emitted by the tube depends upon the gas used in it. The regulator is fitted with some chemical arrangement whereby the proper gas is admitted to it when the tube is in operation. Nitrogen is employed when the tube gives the highest efficiency and the light emitted when this gas is used is yellowish in color. Air gives a pink appearance to the tube and carbon dioxide is employed when a white light is desired.

Table IX gives general data on the Moore tube light. The advantages claimed for this light are: High efficiency, good color, and low intrinsic brilliancy.

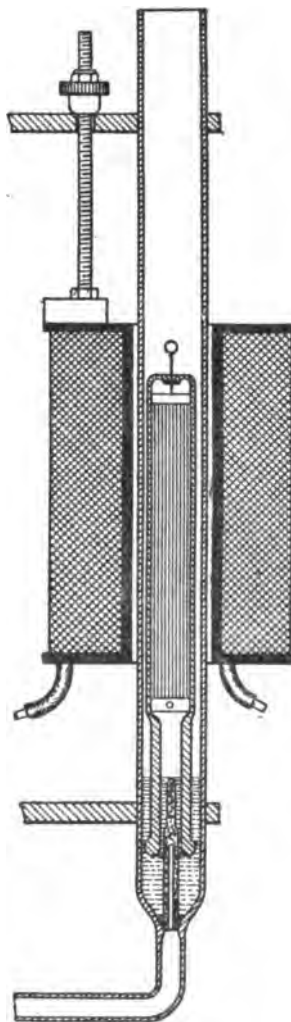


Fig. 31. Regulating Valve.

TABLE IX
Data on the Moore Tube Light

LENGTH OF TUBE	TRANSFORMER CAPACITY	POWER FACTOR OF CIRCUIT	VOLTAGE AT LAMP TERMINALS
40-70 ft.	2 kw.	65-84%	3,146 for 40-ft. tube, at 12 hefners per ft.
80-125 "	2.75 "		
130-180 "	3.5 "		
190-220 "	4.5 "		12,441 for 220-ft. tube, at 12 hefners per ft.

Pressure in tube, about $\frac{1}{15}$ m.m.

Watts per hefner, 3.2 for 20-foot tube including transformer.

Watts per hefner, 1.4 for 180-foot tube including transformer.

Hefner per foot, normal, 12.

Note that one hefner equals 0.88 candle-power.

ARC LAMPS

The Electric Arc. Suppose two carbon rods are connected in an electric circuit, and the circuit closed by touching the tips of these rods together; on separating the carbons again the circuit will not be broken, provided the space between the carbons be not too great,

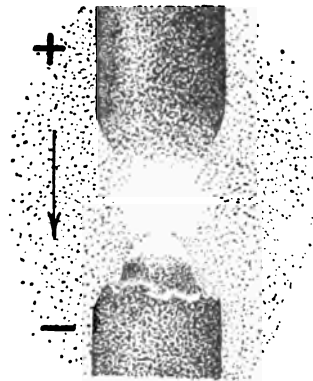


Fig. 32. The Electric Arc between Carbon Terminals.

but will be maintained through the arc formed at these points. This phenomenon, which is the basis of the arc light, was first observed on a large scale by Sir Humphrey Davy, who used a battery of 2,000 cells and produced an arc between charcoal points four inches apart.

As the incandescence of the carbons across which an arc is maintained, together with the arc itself, forms the source of light for a large portion of arc lamps, it will be well to study the nature of the arc. Fig. 32 shows the general appearance of an arc between two carbon electrodes when maintained by direct current.

Here the current is assumed as passing from the top carbon to the bottom one as indicated by the arrow and signs. We find, in the direct-current arc, that the most of the light issues from the tip of the positive carbon, or electrode, and this portion is known as the *crater* of the arc. This crater has a temperature of from $3,000^{\circ}$ to $3,500^{\circ}$ C., the temperature at which the carbon vaporizes, and gives fully 80 to 85% of the light furnished by the arc. The negative carbon becomes pointed at the same time that the positive one is hollowed out to form the crater, and it is also incandescent but not to as great a degree as the positive carbon. Between the electrodes there is a band of violet light, the *arc proper*, and this is surrounded by a luminous zone of a golden yellow color. The arc proper does not furnish more than 5% of the light emitted when pure carbon electrodes are used.

The carbons are worn away or consumed by the passage of the current, the positive carbon being consumed about twice as rapidly as the negative.

The light distribution curve of a *direct-current arc*, taken in a vertical plane, is shown in Fig. 33. Here it is seen that the maximum amount of light is given off at an angle of about 50° from the vertical, the negative carbon shutting off the rays of light that are thrown directly downward from the crater.

If alternating current is used, the upper carbon becomes positive and negative alternately, and there is no chance for a crater to be formed, both carbons giving off the same amount of light and being consumed at about the same rate. The light distribution curve of an *alternating-current arc* is shown in Fig. 34.

Arc-Lamp Mechanisms. In a practical lamp we must have not only a pair of carbons for producing the arc, but also means for supporting these carbons, together with suitable arrangements for leading

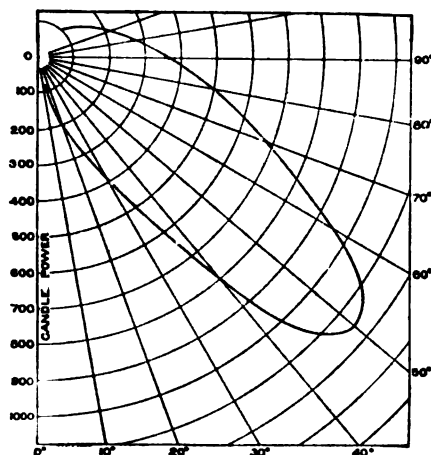


Fig. 33. Distribution Curve for D. C. Arc Lamp (Vertical Plane).

the current to them and for maintaining them at the proper distance apart. The carbons are kept separated the proper distance by the operating mechanisms which must perform the following functions:

1. The carbons must be in contact, or be brought into contact, to start the arc when the current first flows.
2. They must be separated at the right distance to form a proper arc immediately afterward.

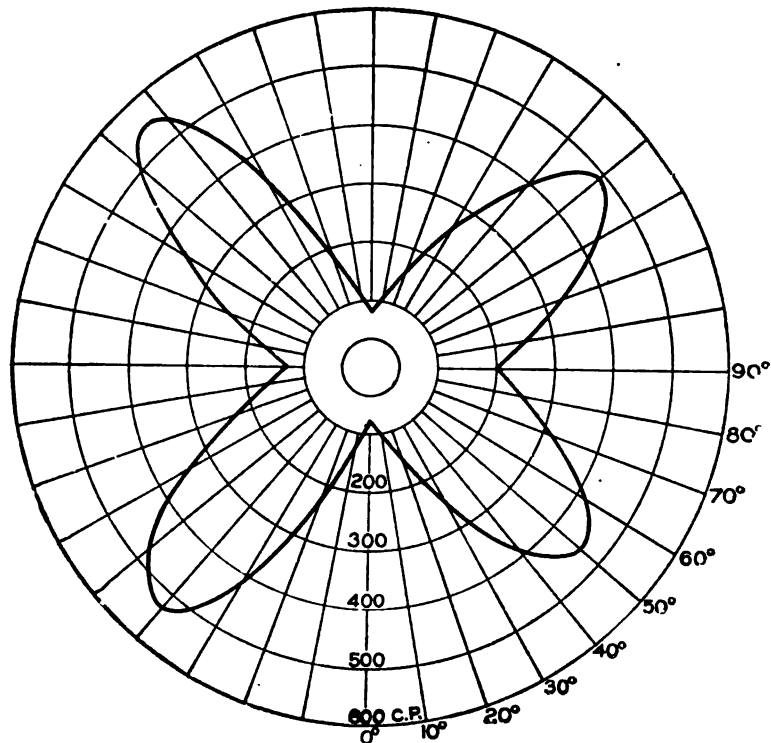


Fig. 34. Distribution Curve for A. C. Arc Lamp (Vertical Plane).

3. The carbons must be fed to the arc as they are consumed.
4. The circuit should be open or closed when the carbons are entirely consumed, depending on the method of power distribution.

The feeding of the carbons may be done by hand, as is the case in some stereopticons using an arc, but for ordinary illumination the striking and maintaining of the arc must be automatic. It is made so in all cases by means of solenoids acting against the force of gravity or against springs. There are an endless number of such mechanisms,



SIMPLE COMBINATION GAS AND ELECTRIC FIXTURE IN A DINING ROOM

but a few only will be described here. They may be roughly divided into three classes:

1. Shunt mechanisms.
2. Series mechanisms.
3. Differential mechanisms.

Shunt Mechanisms. In shunt lamps, the carbons are held apart before the current is turned on, and the circuit is closed through a solenoid connected in across the gap so formed. All of the current must pass through this coil at first, and the plunger of the solenoid is arranged to draw the carbons together, thus starting the arc. The pull of the solenoid and that of the springs are adjusted to maintain the arc at its proper length.

Such lamps have the disadvantage of a high resistance at the start—450 ohms or more—and are difficult to start on series circuits, due to the high voltage required. They tend to maintain a constant voltage at the arc, but do not aid the dynamo in its regulation, so that the arcs are liable to be a little unsteady.

Series Mechanisms. With the series-lamp mechanism, the carbons are together when the lamp is first started and the current, flowing in the series coil, separates the electrodes, striking the arc. When the arc is too long, the resistance is increased and the current lowered so that the pull of the solenoid is weakened and the carbons feed together. This type of lamp can be used only on constant-potential systems.

Fig. 35 shows a diagram of the connection of such a lamp. This diagram is illustrative of the connection of one of the lamps manufactured by the Western Electric Company, for use on a direct-current,

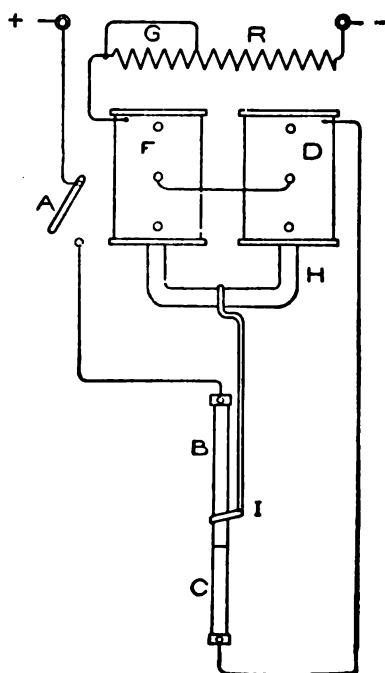


Fig. 35. Series Mechanism for D. C. Arc Lamp.

constant-potential system. The symbols + and - refer to the terminals of the lamp, and the lamp must be so connected that the current flows from the top carbon to the bottom one. R is a series resistance, adjustable for different voltages by means of the shunt G . F and D are the controlling solenoids connected in series with the arc. B and C are the positive and negative carbons respectively, while A is the switch for turning the current on and off. H is the plunger of the

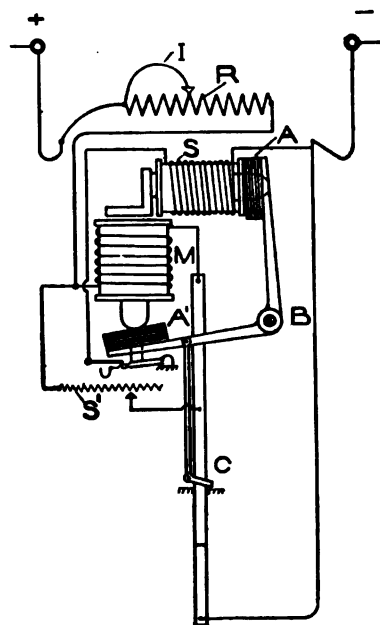


Fig. 36. Differential Mechanism for D. C. Arc Lamp.

solenoids and I the carbon clutch, this being what is known as a *carbon-feed lamp*. The carbons are together when A is first closed, the current is excessive, and the plunger is drawn up into the solenoids, lifting the carbon B until the resistance of the arc lowers the current to such a value that the pull of the solenoid just counterbalances the weight of the plunger and carbon. G must be so adjusted that this point is reached when the arc is at its normal length.

Differential Mechanisms. In the differential lamp, the series and shunt mechanisms are combined, the carbons being together at the start, and the series coil arranged so as to separate them while the shunt coil is connected across the

arc, as before, to prevent the carbons from being drawn too far apart. This lamp operates only over a low-current range, but it tends to aid the generator in its regulation.

Fig. 36 shows a lamp having a differential control, this also being the diagram of a Western Electric Company arc lamp for a direct-current, constant-potential system. Here S represents the shunt coil and M the series coil, the armature of the two magnets A and A' being attached to a bell-crank, pivoted at B , and attached to the carbon clutch C . The pull of coil S tends to lower the carbon while that of M raises the carbon, and the two are so adjusted that equilibrium is

reached when the arc is of the proper length. All of the lamps are fitted with an air dashpot, or some damping device, to prevent too rapid movements of the working parts.

The methods of supporting the carbons and feeding them to the arc may be divided into two classes:

1. Rod-feed mechanism.
2. Carbon-feed mechanism.

Rod-Feed Mechanism.

Lamps using a rod feed have the upper carbons supported by a conducting rod, and the regulating mechanism acts on this rod, the current being fed to the rod by means of a sliding contact. Fig. 37 shows the arrangement of this type of feed. The rod is shown at *R*, the sliding contact at *B*, and the carbon is attached to the rod at *C*.

These lamps have the advantage that carbons, which do not have a uniform cross-section or smooth exterior, may be used, but they possess the disadvantage of being very long in order to accommodate the rod. The rod must also be kept clean so as to make a good contact with the brush.

Carbon-Feed Mechanism. In carbon-feed lamps the controlling mechanism acts on the carbons directly through some form of clutch such as is shown at *C* in Fig. 38. This clamp grips the carbon when it is lifted, but allows the carbon to slip through it when the tension is released. For this type of feed the carbon must be straight and have a uniform cross-section as well as a smooth exterior. The current may be led to the carbon by means of a flexible lead and a short carbon holder.

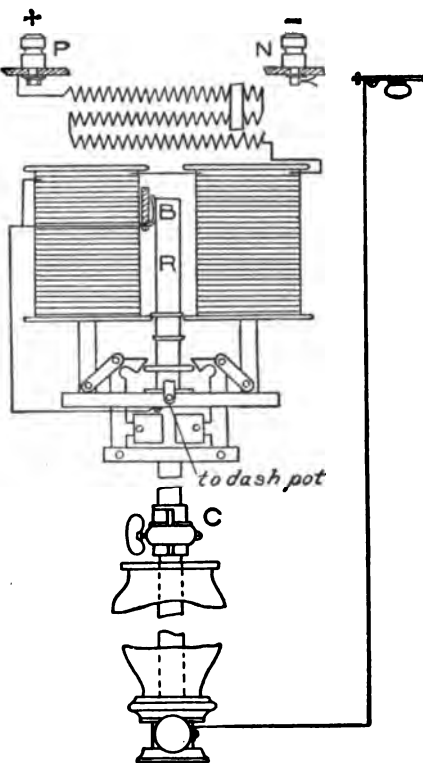


Fig. 37. Rod-Feed Mechanism.

TYPES OF ARC LAMPS

Arc lamps are constructed to operate on *direct-current* or *alternating-current* systems when connected in *series* or in *multiple*. They are also made in both the *open* and the *enclosed* forms.

By an *open arc* is meant an arc lamp in which the arc is exposed to the atmosphere, while in the *enclosed arc* an inner or enclosing

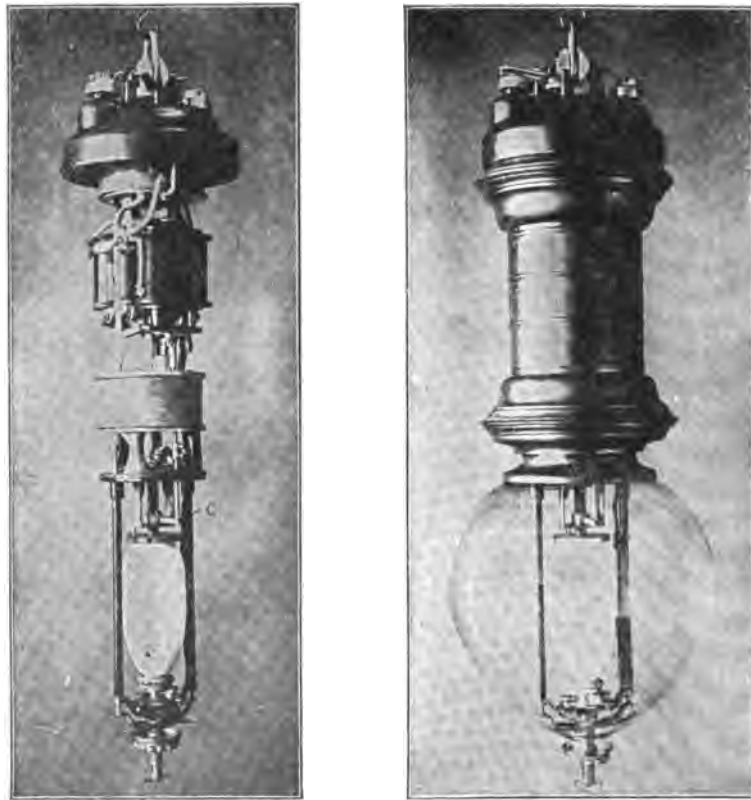


Fig. 38. Enclosed Arc Lamp with Carbon-Feed Mechanism.

globe surrounds the arc, and this globe is covered with a cap which renders it nearly air-tight. Fig. 38 is a good example of an enclosed arc as manufactured by the General Electric Company.

Direct-Current Arcs. *Open Types of Arcs* for direct-current systems were the first to be used to any great extent. When used they are always connected in series, and are run from some form of

special arc machine, a description of which may be found in "Types of Dynamo Electric Machinery."

Each lamp requires in the neighborhood of 50 volts for its operation, and, since the lamps are connected in series, the voltage of the system will depend on the number of lamps; therefore, the number of lamps that may be connected to one machine is limited by the maximum allowable voltage on that machine. By special construction as many as 125 lamps are run from one machine, but even this size of generator is not so efficient as one of greater capacity. Such generators are usually wound for 6.6 or 9.6 amperes. Since the carbons are exposed to the air at the arc, they are rapidly consumed, requiring that they be renewed daily for this type of lamp.

Double-carbon arcs. In order to increase the life of the early form of arc lamp without using too long a carbon, the double-carbon type was introduced. This type uses two sets of carbons, both sets being fed by one mechanism so arranged that when one pair of the electrodes is consumed the other is put into service. At present nearly all forms of the open arc lamp have disappeared on account of the better service rendered by the enclosed arc.

Enclosed arcs for series systems are constructed much the same as the open lamp, and are controlled by either shunt or differential mechanism. They require a voltage from 68 to 75 at the arc, and are usually constructed for from 5 to 6.8 amperes. They also require a constant-current generator or a rectifier outfit if used on alternating-current circuits.

Constant-potential arcs must have some resistance connected in series with them to keep the voltage at the arc at its proper value. This resistance is made adjustable so that the lamps may be used on any circuit. Its location is clearly shown in Fig. 38, one coil being located above, the other below the operating solenoids.

Alternating-Current Arcs. These do not differ greatly in construction from the direct-current arcs. When iron or other metal parts are used in the controlling mechanism, they must be laminated or so constructed as to keep down induced or eddy currents which might be set up in them. For this reason the metal spools, on which the solenoids are wound, are slotted at some point to prevent them from forming a closed secondary to the primary formed by the solenoid winding. On constant-potential circuits a reactive coil is used

in place of a part of the resistance for cutting down the voltage at the arc.

Interchangeable Arc. Interchangeable arcs are manufactured which may be readily adjusted so as to operate on either direct or alternating current, and on voltages from 110 to 220. Two lamps may be run in series on 220-volt circuits.

The distribution of light, and the resulting illumination for the different lamps just considered, will be taken up later. Aside from the distribution and quality of light, the enclosed arc has the advantage that the carbons are not consumed so rapidly as in the open lamp because the oxygen is soon exhausted from the inner globe and the combustion of the carbon is greatly decreased. They will burn from 80 to 100 hours without retrimming.

TABLE X
Rating of Enclosed Arcs

D. C. LAMP	CURRENT	WATTS CONSUMED			MEAN INTENSITY IN H. U.			MEAN WATTS		
		IN LAMP	IN ARC	MECHANISM	SPHERICAL		LOWER HEMI- SPHERI- CAL	SPHERICAL H. U.		LOWER HEMI- SPHERI- CAL
					OPAL OUTER	CLEAR OUTER		OPAL OUTER	CLEAR OUTER	
1	5.01	551	401	150	172	235	332	3.10	2.37	1.66
3	5.08	559	406	252	195	256*	362*	2.85	2.18*	1.52*
4	4.76	524	381	143	127	216	282	4.12	2.60	1.99
5	4.16†	458	333	125	154	139	208	2.96	3.76	2.52
7	4.76	524	381	143	203	333	317	2.63	2.63	2.07
9	4.84	532	387	145	182	226	281	2.83	2.20	1.65
10	4.99	549	399	150	202	242	309	2.74	2.38	1.89
12	4.87	536	390	146	178	195	230	3.05	2.24	1.77
Mean	4.9	529	384	144	176	207	272	3.03	2.66	2.33
								2.60		1.98

A. C. LAMP	CURRENT	IN LAMP	POWER FACTOR LAMP	IN ARC	POWER FACTOR ARC	MECHANISM					
101	6.40	448	.63	340	.82	108	127	141	206	3.52	2.17
								203	236		2.26
102	6.79	459	.61	375	.73	84	146	176†	226†	3.31	2.60†
103	5.89	424	.65	344	.75	80	116	130	147	3.66	3.15
105	6.20	414	.61	382	.80	32	128	187	219	3.24	2.20
								153	169		2.56
106	6.12	378	.56	298	.70	80	132	182†	284	2.82	2.10†
108	6.48	457	.64	383	.80	74.5	133	175	211	3.20	2.61
110	6.18	339	.49	276	.72	63	140*	126	143	2.41*	2.68
Mean	6.29	417	.60	342	.76	74.5	130	159	190	3.31	2.66
											2.37
											2.23

*Condition of no outer globe. †Condition with shade on lamp. H.U. Hefner Units.

Rating of Arc Lamps. Open arcs have been classified as follows:

Full Arcs, 2,000 candle-power taking 9.5 to 10 amps. or 450–480 watts.

Half Arcs, 1,200 candle-power taking 6.5 to 7 amps. or 325–350 watts.

These candle-power ratings are much too high, and run more nearly 1,200 and 700, respectively, for the point of maximum intensity and less than this if the mean spherical candle-power be taken. For this reason, the ampere or watt rating is now used to indicate the power of the lamp. It is now recommended that specifications for street lighting should be based upon the illumination produced. This point is considered later under the topic of street lighting. Enclosed arcs use from 3 to 6.5 amperes, but the voltage at the arc is higher than for the open lamp. Table X gives some data on enclosed arcs on constant-potential circuits.

Efficiency. The efficiency of arc lamps is given as follows:

Direct-Current Arc (enclosed) 2.9 watts per candle-power.

Alternating-Current Arc (enclosed) 2.95 watts per candle-power.

Direct-Current Arc (open) .6–1.25 watts per candle-power.

Carbons for Arc Lamps. Carbons are either moulded or forced from a product known as *petroleum coke* or from similar materials such as *lampblack*. The material is thoroughly dried by heating to a high temperature, then ground to a fine powder, and combined with some substance such as pitch which binds the fine particles of carbon together. After this mixture is again ground it is ready for moulding. The powder is put in steel moulds and heated until it takes the form of a paste, when the necessary pressure is applied to the moulds. For the forced carbons, the powder is formed into cylinders which are placed in machines which force the material through a die so arranged as to give the desired diameter. The forced carbons are often made with a core of some special material, this core being added after the carbon proper has been finished. The carbons, whether moulded or forced, must be carefully baked to drive off all volatile matter. The forced carbon is always more uniform in quality and cross-section, and is the type of carbon which must be used in the carbon-feed lamp. The adding of a core of a different material seems to change the quality of light, and being more readily volatilized, keeps the arc from wandering.

Plating of carbons with copper is sometimes resorted to for moulded forms for the purpose of increasing the conductivity, and, by protecting the carbon near the arc, prolonging the life.

The Flaming Arc. In the carbon arc the arc proper gives out but a small percentage of the total amount of light emitted. In order to obtain a light in which more of the source of luminosity is in the arc itself, experiments have been made with the use of electrodes impregnated with certain salts, as well as with electrodes of a material different than carbon. The result of these experiments has been to place upon the market the flaming arc lamps and the luminous arc lamps—lamps of high candle-power, good efficiency, and giving various colors of light. These lamps may be put in two classes: One class uses carbon electrodes, these electrodes being impregnated with certain

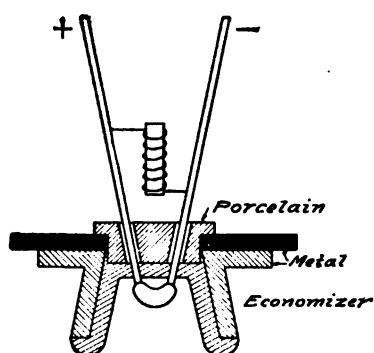


Fig. 39. Diagram of Bremer Flaming Arc.

salts which add luminosity to the arc, or else fitted with cores which contain the required material; the other class covering lamps which do not employ carbon, the most notable example being the magnetite arc which uses a copper segment as one electrode and a magnetite stick as the other electrode.

Flaming arcs of the first class are made in two general types:

One in which the electrodes are placed at an angle, and the other in which the carbons are placed one above the other as in the ordinary arc lamp. The term luminous arc is usually applied to arcs of the flaming type in which the electrodes are placed one above the other. The minor modifications as introduced by the various manufacturers are numerous and include such features as a magazine supply of electrodes by which a new pair may be automatically introduced when one pair is consumed; feed and control mechanisms; etc. The flaming arc presents a special problem since the vapors given off by the lamp may condense on the glassware and form a partially opaque coating, or they may interfere with the control mechanism.

Bremer Arc. The Bremer flaming arc lamp was introduced commercially in 1899, and since some of its principles are incorporated in many of the lamps on the market to-day, it will be briefly described here. The diagram shown in Fig. 39 illustrates the main features of

this lamp. The electrodes are mounted at an angle and an electromagnet is placed above the arc for the purpose of keeping the arc from creeping up and injuring the economizer, and also for the purpose of spreading the arc out and increasing its surface. The vapor from the arc is condensed on the economizer and this coating acts as a reflector, throwing the light downward. The economizer serves to limit the air supplied to the arc and thus increases the life of the electrodes. The inclined position of the carbons was suggested by the fact that in the impregnated carbons a slag was formed which gave trouble when the electrodes were mounted in the usual manner. By using the electrodes in this position there is little if any obstruction to the light which passes directly downward from the arc.

Bremer's original electrodes contained compounds of calcium, strontium, magnesium, etc., as well as boracic acid. Electrodes as employed in the various lamps to-day differ greatly in their make-up. Some use impregnated

carbons, others use carbons with a core containing the flaming materials, and metallic wires are added in some cases. The life of electrodes for flaming lamps is not great, depending upon their length and somewhat upon the type of lamp. The maximum life of the treated carbons is in the neighborhood of 20 hours.

The color of the light from the flaming arc is yellow when calcium salts are used as the main impregnating compound, and the majority of the lamps installed use electrodes giving a yellow light. By employing more strontium, a red or pink light is produced, while if a white light is wanted, barium salts are used. Calcium gives the most efficient service and strontium comes between this and barium. The distribution curves in Fig. 40 illustrate the relative economies

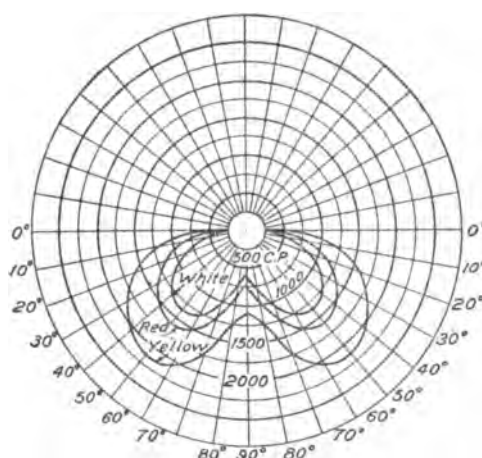


Fig. 40. Distribution Curves of a Luminous Arc.

of the different materials. Modern electrodes contain not more than 15% of added material and it is customary to find the salts applied as a core to the pure carbon sticks. The electrodes are made of a small diameter in order to maintain a steady light and this partially accounts for their short life.

The feeding mechanisms employed differ greatly. They may be classified as: Clock, gravity-feed, clutch, motor, and hot-wire mechanisms. Fig. 41 illustrates a clock mechanism. This is a dif-

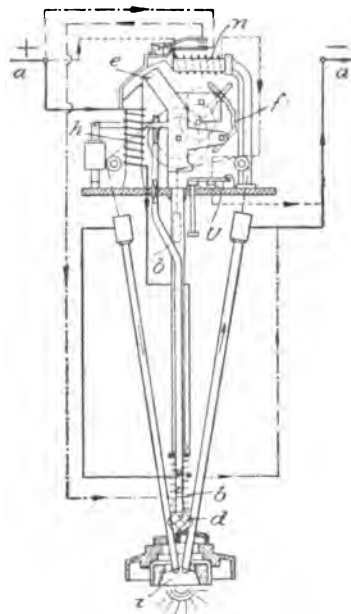


Fig. 41. Clock Feeding Mechanism for Luminous Arc Lamp.

ferential mechanism in which the shunt coils act to release a detent f which allows the electrodes to feed down and when they come in contact the series coils separate them to the proper extent for maintaining a suitable arc. In the gravity feed an electromagnet is used to operate one carbon in springing the arc and the other carbon is fed by gravity, it being prevented from dropping too far by means of a special rib formed on the electrode which comes in contact with a part of the lamp structure. Gravity feed is also employed in the clutch mechanism but here the carbons are held in one position by an electrically operated clutch which releases them only when the current is sufficiently reduced by the lengthening of the arc. In the

hot-wire lamp, the wire is usually in series with the arc; the contraction and expansion of this wire is balanced against a spring and the arc is regulated by such contraction or expansion of the wire. Such a lamp is suitable for either direct or alternating current. In the motor mechanism, as applied to alternating-current lamps, a metallic disk is actuated by differential magnets and its motion is transmitted to the electrodes to lengthen or shorten the arc accordingly as the force exerted by the series or shunt coils predominates.

Magnetite Arc. The magnetite arc employs a copper disk as

one electrode; and a magnetite stick—formed by forcing magnetite, to which titanium salts are usually added, into a thin sheet steel tube—is used as the other electrode. This lamp gives a luminous arc of good efficiency and the magnetite electrode is not consumed as rapidly as the treated carbons with the result that magnetite lamps do not require trimming as frequently. The life of the magnetite electrode as at present manufactured is from 170 to 200 hours. A diagram of the connections of this lamp as manufactured by the General Electric

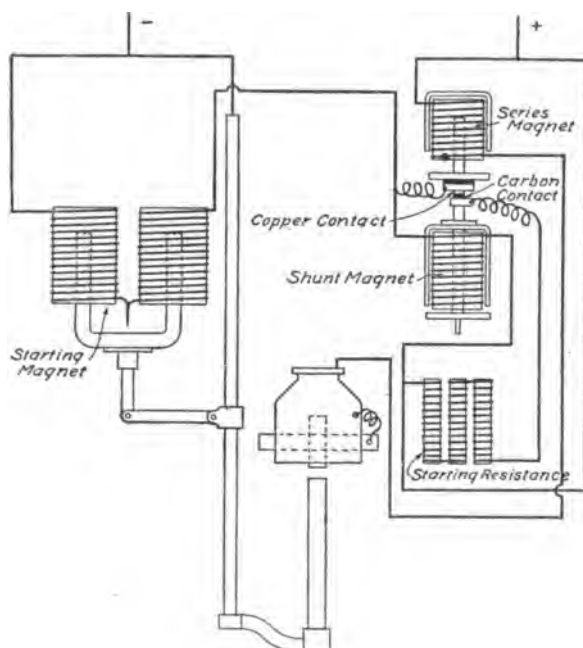


Fig. 42. Diagram of Connections for Magnetite Arc Lamp.

Company is shown in Fig. 42. The magnetite electrode is placed below. The copper electrode has just the proper dimensions to prevent its being destroyed by the arc and yet it is not large enough to cause undue condensation of the arc vapor. Direct current must be used with this lamp, the current passing from the copper to the magnetite.

Table XI gives some general data on the flaming arc, while Figs. 43 and 44 give typical distribution curves. The advantages of the flaming arc over lamps using pure carbon electrodes are: High efficiency; better light distribution; and better color of light for some

purposes. A greater amount of light can be obtained from a single unit than is practical with the carbon arc. The disadvantages lie in the frequent trimming required and the expense of electrodes. Flaming arcs have been introduced abroad, especially in Germany, to a much greater extent than in the United States.

TABLE XI
General Data on Flaming Arcs

VOLTS	AMPERES	WATTS	MEAN SPHERICAL CANDLE-POWER	WATTS PER MEAN SPHERICAL C. P.
55	6	330	480	.68
	8	440	800	.55
	10	550	1100	.5
	12	660	1300	.5
	15	825	1700	.49
	20	1100	2250	.48

POWER DISTRIBUTION

The question of power distribution for electric lamps and other appliances is taken up fully in the section on that subject, therefore it will be treated very briefly here. The systems may be divided into:

1. Series distribution systems.
2. Multiple-series or series-multiple systems.
3. Multiple or parallel systems.

They apply to both alternating and direct current.

The Series System. This is the most simple of the three; the lamps, as the name indicates, are connected in series as shown in Fig. 45. A constant load is necessary if a constant potential is to be used. If the load is variable, a constant-current generator, or a special regulating device is necessary. Such devices are constant-current transformers and constant-current regulators as applied to alternating-current circuits.

The series system is used mostly for arc and incandescent lamps when applied to street illumination. Its advantages are simplicity and saving of copper. Its disadvantages are high voltage, fixed by the number of lamps in series; the size of the machines is limited since they cannot be insulated for voltage above about 6,000; a single open circuit shuts down the whole system.

Alternating-current series distribution systems are being used to a very large extent. By the aid of special transformers, or regulators,

any number of circuits can be run from one machine or set of bus bars, and apparatus can be built for any voltage and of any size. It is not customary, however, to build transformers of this type having a capac-

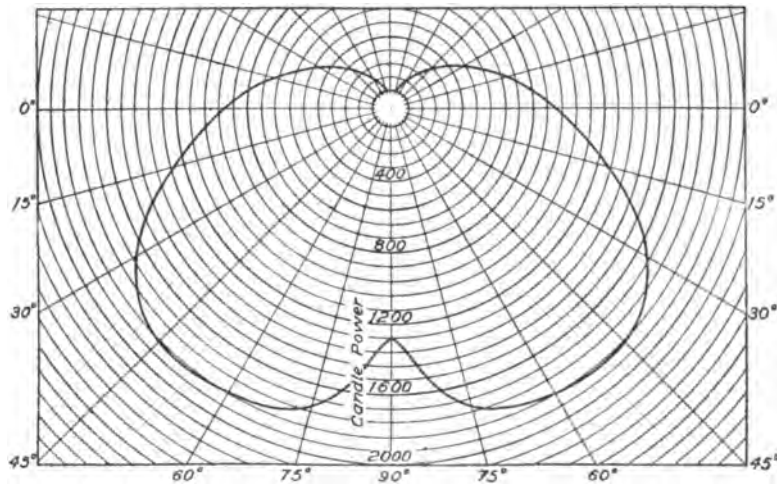


Fig. 43. Distribution Curve for Flaming Arc Lamp.

ity greater than one hundred 6.6-ampere lamps because of the high voltage which would have to be induced in the secondary for a larger number of lamps.

Fig. 45 gives a diagram of the connection of a single-coil transformer in service. The constant-current transformer most in use for lighting purposes is the one manufactured by the General Electric Company and commonly known as a *tub transformer*. Fig. 46 shows such a transformer (double-coil type) when removed from the case.

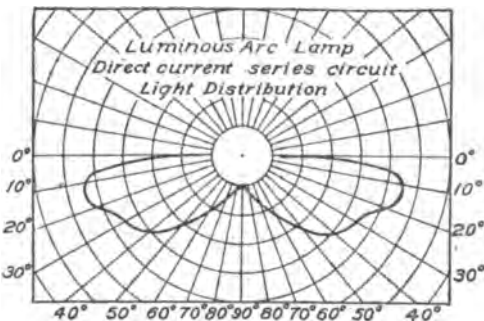


Fig. 44. Distribution Curve for a 4-Ampere, 75-Volt, Magnetite Luminous Arc Lamp.

Referring to Fig. 46, the fixed coils *A* form the primaries which are connected across the line; the movable coils *B* are the secondaries

connected to the lamps. There is a repulsion of the coils *B* by the coils *A* when the current flows in both circuits and this force is balanced by means of the weights at *W*, so that the coils *B* take a position such that the normal current will flow in the secondary. On light loads, a low voltage is sufficient, hence the secondary coils are close

together near the middle of the machine and there is a heavy magnetic leakage. When all of the lamps are on, the coils take the position shown when the leakage is a minimum and the voltage a maximum. When first starting up, the transformer is short-circuited and the secondary coils brought close together. The short circuit is then removed and the coils take a position corresponding to the load on the line.

These transformers regulate from full load to $\frac{1}{3}$ rated load within $\frac{1}{10}$ ampere of normal current, and can be run on short circuit for several hours without overheating. The efficiency is given as 96% for 100-light transformers and 94.6% for 50-light transformers at full

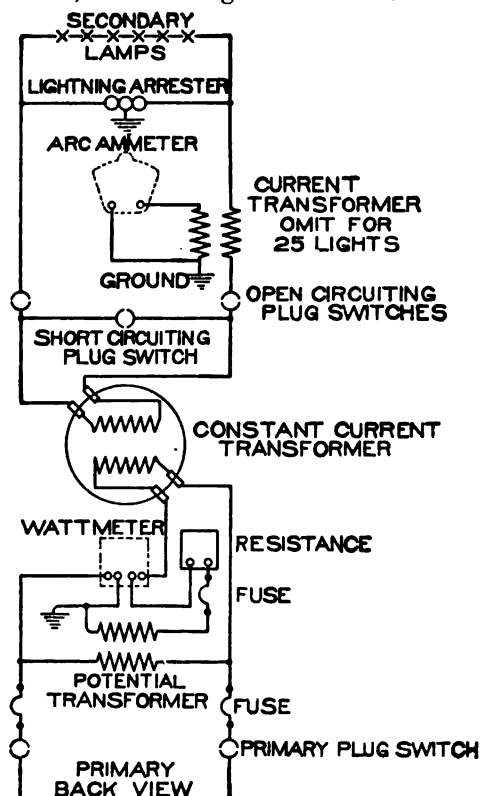


Fig. 45. Wiring Diagram for Single-Coil Transformer.

load. The power factor of the system is from 76 to 78% on full load, and, owing to the great amount of magnetic leakage at less than full load—the effect of leakage being the same as the effect of an inductance in the primary—the power factor is greatly reduced, falling to 62% at $\frac{3}{4}$ load, 44% at $\frac{1}{2}$ load, and 24% at $\frac{1}{4}$ load.

Standard sizes are for capacities of 25-, 35-, 50-, 75-, and 100-6.6 ampere enclosed arcs, and they are also made for lower currents in

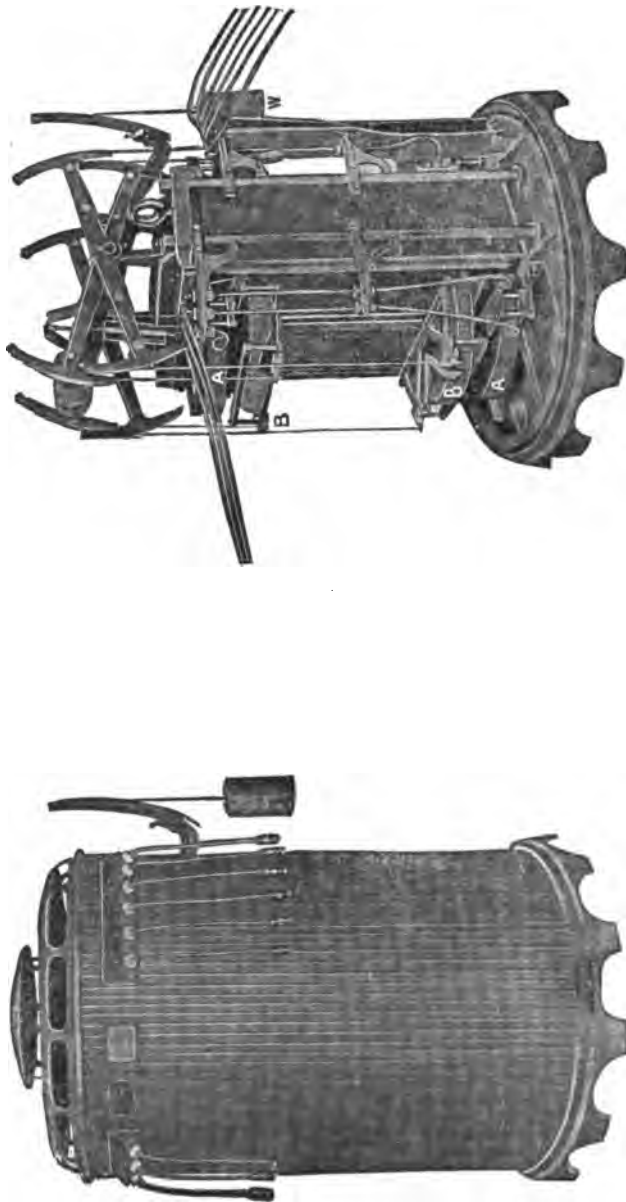


Fig. 46. Double-Coil Transformer (second view with case removed).

the neighborhood of 3.3 amperes for incandescent lamps. The low power factor of such a system on light loads shows that a transformer should be selected of such a capacity that it will be fully or nearly fully loaded at all times. The primary winding can be constructed for any voltage and the open circuit voltages of the secondaries are as follows:

25 light transformer, 2,300 volts.	75 light transformer, 6,900 volts.
35 " " 3,200 "	100 " " 9,200 "
50 " " 4,600 "	

The 50-, 75-, and 100-light transformers are arranged for multiple circuit operation, two circuits used in series, and the voltages at full load reach 4,100 for each circuit on the 100-light machine.

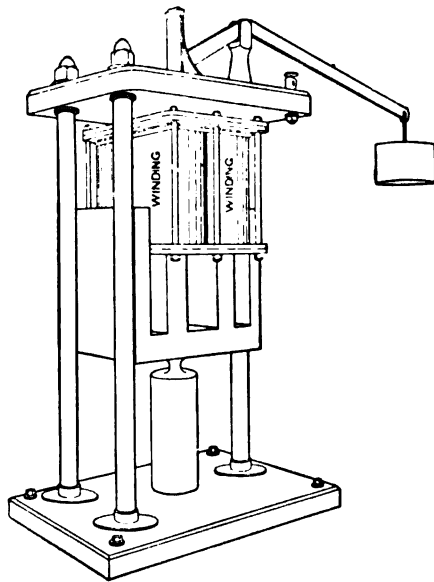


Fig. 47. Current Regulator for A. C. Series Distribution Systems.

The second system, used for series distribution on alternating-current circuits consists of a constant-potential transformer, stepping down the line voltage to that required for the total number of lamps on the system, allowing 83 volts for each lamp, and in series with the lamps is a reactive coil, the reactance of which is automatically regulated, as the load is increased or decreased, in order to keep the current in the line constant. Fig. 47 shows such a regulator and Fig. 48 shows this regulator connected in circuit. The inductance is varied by the movement of the coil so as to include more or less iron in the magnetic circuit. Since the inductance in series with the lamps is high on light loads, the power factor is greatly reduced as in the constant-current transformer; and the circuits should, preferably, be run fully loaded. 60 to 65 lamps on a circuit is the usual maximum limit.

While used primarily for arc-light circuits, the same systems,





ELECTRICAL KITCHEN IN EDISON BUILDING, CHICAGO

designed for lower currents, are very readily applied to series incandescent systems.

The introduction of certain flaming or luminous arcs requiring direct current for their operation has led to the use of the *mercury arc rectifier* in connection with series circuits on alternating-current systems. A constant-current transformer is used to regulate for the proper constant current in its secondary winding, and this secondary current is rectified by means of the mercury arc rectifier for the lamp circuit. In the recent outfits the rectifier tubes are immersed in oil for cooling. While this rectifier was first introduced for the operation of luminous arc lamps, there is no reason why it should not be used with any series lamp requiring direct current, provided the system is designed for the current taken by such lamps. With this system any commercial frequency may be used. Sets are constructed for 25-, 50-, and 75-light circuits. They have a combined efficiency, transformer and rectifier tube, of 85% to 90%, and operate at a power factor of from 65% to 70%. Fig. 49 gives a diagram of the circuit and rectifier connections used with a single-tube outfit.

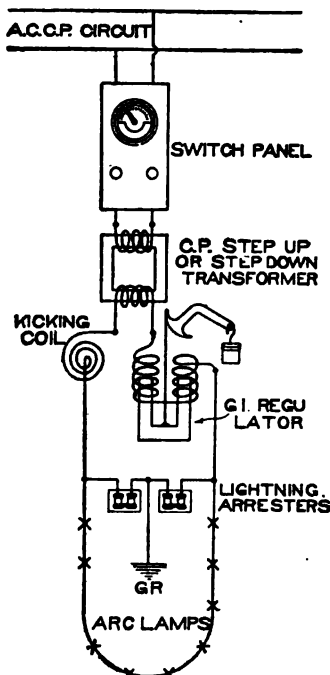


Fig. 48. Wiring Diagram Showing Introduction of the Current Regulator.

Multiple-Series or Series-Multiple Systems. These combine several lamps in series, and these series groups in multiple, or several lamps in multiple and these multiple groups in series, respectively. They have but a limited application.

Multiple or Parallel Systems of Distribution. By far the largest number of lamps in service are connected to parallel systems of distribution. In this system, the units are connected across the lines leading to the bus bars at the station, or to the secondaries of constant-potential transformers. Fig. 50 shows a diagram of ten lamps connected in parallel. The current delivered by the machine de-

depends directly on the number of lamps connected in service, the voltage of the system being kept constant.

Inasmuch as the flow of current in a conductor is always accom-

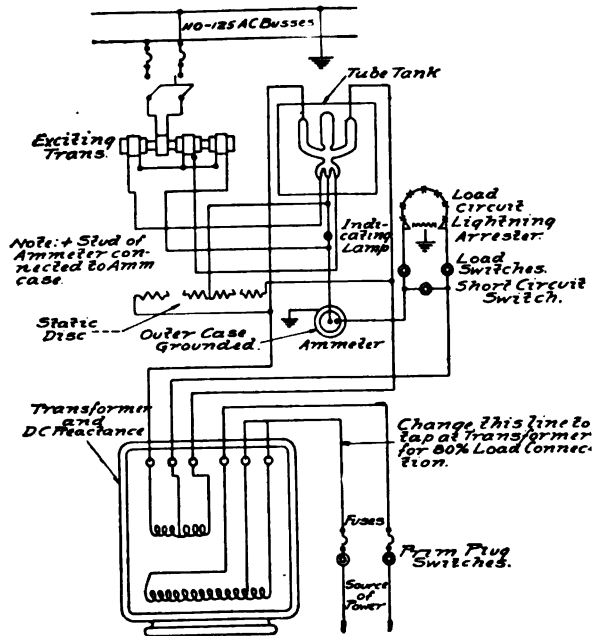


Fig. 49. Wiring Diagram for A. C. System Showing Introduction of Mercury Arc Rectifier.

various schemes have been adopted to aid in this regulation. The systems may be classified as:

1. Cylindrical conductors, parallel feeding.
2. Conical " " "
3. Cylindrical " anti-parallel feeding.
4. Conical " " "

In the cylindrical conductor, parallel-feeding system, the conductors, *A, B, C, D*, Fig. 50, are of the same size throughout and are fed at the same end by the generator. The voltage is a minimum at the lamps *E* and a maximum at the lamps *F*; the value of the voltage at any lamp being readily calculated.

By a *conical* or *tapering conductor* is meant a conductor whose diameter is so proportioned throughout its length that the current, divided by the cross-section, or the current density, is a constant

panied by a fall of potential equal to the product of the current flowing into the resistance of the conductor, the lamps at the end of the system shown will not have as high a voltage impressed upon them as those nearer the machine. This drop in potential is the most serious obstacle that we have to overcome in multiple systems, and

quantity. Such a conductor is approximated in practice by using smaller sizes of wire as the current in the lines becomes less.

In an anti-parallel system, the current is fed to the lamps from opposite ends of the system, as shown in Fig. 51.

Multiple-Wire Systems. In order to take advantage of a higher voltage for distribution of power to the lighting circuits, three- and five-wire systems have been introduced, the three-wire system being used to a very large extent. In this system, three conductors are used, the voltage from each outside conductor to the middle neutral conductor being the same as for a simple parallel system. Fig. 52 gives a diagram of this. By this system the amount of copper required for a given number of lamps is from five-sixteenths to three-eighths of the amount required for a two-wire distribution, depending on the size of the neutral conductor. The saving of copper together with the disadvantages of the system is more fully treated in the paper on "Power Transmission."

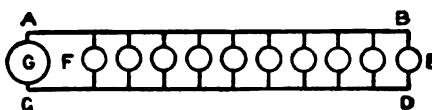


Fig. 50. Parallel Feeding System.

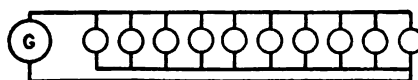


Fig. 51. Anti-parallel Feeding System.

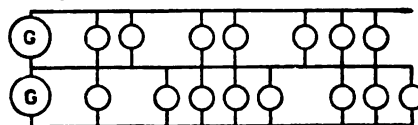


Fig. 52. Three-wire System.

ILLUMINATION

Illumination may be defined as the quality and quantity of light which aids in the discrimination of outline and the perception of color. Not only the quantity, but the quality of the light, as well as the arrangement of the units, must be considered in a complete study of the subject of illumination.

Unit of Illumination. The unit of illumination is the *foot-candle* and its value is the amount of light falling on a surface at a distance of one foot from a source of light one candle-power in value. The law of inverse squares—namely, that the illumination from a given source varies inversely as the square of the distance from the source—shows that the illumination at a distance of two feet from a

single candle-power unit is .25 foot-candles. For further consideration of the law of inverse squares, see "Photometry."

Illumination may be classified as *useful*—when used for the ordinary purposes of furnishing light for carrying on work, taking the place of daylight; and *scenic*—when used for decorative lighting such as stage lighting, etc. The two divisions are not, as a rule, distinct, but the one is combined with the other.

Intrinsic Brightness. By intrinsic brightness is meant the amount of light emitted per unit surface of the light source. Table XII gives the intrinsic brightness of several light sources.

TABLE XII
Intrinsic Brilliances in Candle-Power per Square Inch

SOURCE	BRILLIANCY	NOTES
Sun in zenith	600,000	Rough equivalent values, taking account of absorption
Sun at 30 degrees elv.	500,000	
Sun on horizon	2,000	
	10,000	
Arc light	to 100,000	Maximum about 200,000 in crater
Calcium light	5,000	Unshaded
Nernst "glower"	1,000	
Incandescent lamp	200-300	
Enclosed arc	75-100	Opalescent inner globe
Acetylene flame	75-100	Variable
Welsbach light	20 to 25	
Kerosene light	4 to 8	
Candle	3 to 4	Variable
Gas flame	3 to 8	
Incandescent (frosted)	2 to 5	
Opal shaded lamps, etc.	0.5 to 2	

Regular Reflection. Regular reflection is the term applied to reflection of light when the reflected rays are parallel. It is of such a nature that the image of the light source is seen in the reflection. The reflection from a plane mirror is an example of this. It is useful in lighting in that the direction of light may be changed without complicating calculations aside from deductions necessary to compensate for the small amount of light absorbed.

Irregular Reflection. Irregular reflection, or diffusion, consists of reflection in which the reflected rays of light are not parallel but take various directions, thus destroying the image of the light source. Rough, unpolished surfaces give such reflection. Smooth, unpolished surfaces generally give a combination of two kinds of reflection.

Diffused reflection is very important in the study of illumination inasmuch as diffused light plays an important part in the lighting of interiors. This form of reflection is seen in many photometer screens. Light is also diffused when passing through semi-transparent shades or screens.

In considering reflected light, we find that, if the surface on which the light falls is colored, the reflected light may be changed in its nature by the absorption of some of the colors. Since, as has been said, in interior lighting the reflected light forms a large part of the source of illumination, this illumination will depend upon the nature and the color of the reflecting surfaces.

Whenever light is reflected from a surface, either by direct or diffused reflection, a certain amount of light is absorbed by the surface. Table XIII gives the amount of white light reflected from different materials.

TABLE XIII
Relative Reflecting Power

MATERIAL	%
White blotting paper.....	82
White cartridge paper.....	80
Chrome yellow paper.....	62
Orange paper.....	50
Yellow wall paper.....	40
Light pink paper.....	36
Yellow cardboard.....	30
Light blue cardboard.....	25
Emerald green paper.....	18
Dark brown paper.....	13
Vermilion paper.....	12
Blue-green paper.....	12
Black paper.....	5
Black cloth.....	1.2
Black velvet.....	.4

From this table it is seen that the light-colored papers reflect the light well, but of the darker colors only yellow has a comparatively high coefficient of reflection. Black velvet has the lowest value, but this only holds when the material is free from dust. Rooms with dark walls require a greater amount of illuminating power, as will be seen later.

Useful illumination may be considered under the following heads:

1. Residence Lighting.
2. Lighting of Public Halls, Offices, Drafting Rooms, Shops, etc.
3. Street Lighting.

RESIDENCE LIGHTING

Type of Lamps. The lamps used for this class of lighting are limited to the less powerful units—namely, incandescent or Nernst lamps varying in candle-power from 8 to 50 per unit. These should always be shaded so as to keep the intrinsic brightness low. The intrinsic brilliancy should seldom exceed 2 to 3 candle-power per square inch, and its reduction is usually accomplished by appropriate shading. Arc lights are so powerful as to be uneconomical for small rooms, while the color of the mercury-vapor light is an additional objection to its use.

Plan of Illumination. Lamps may be selected and so located as to give a brilliant and fairly uniform illumination in a room; but this is an uneconomical scheme, and the one more commonly employed is to furnish a uniform, though comparatively weak, ground illumination, and to reinforce this at points where it is necessary or desirable. The latter plan is satisfactory in almost all cases and the more economical of the two.

While the use of units of different power is to be recommended, where desirable, lights differing in color should not be used for lighting the same room. As an exaggerated case, the use of arc with incandescent lamps might be mentioned. The arcs being so much whiter than the incandescent lamps, the latter appear distinctly yellow when the two are viewed at the same time.

Calculation of Illumination. In determining the value of illumination, not only the candle-power of the units, but the amount of reflected light must be considered for the given location of the lamps. Following is a formula based on the coefficient of reflection of the walls of the room, which serves for preliminary calculations:

$$I = \frac{c.p. \cdot \frac{1}{1-k}}{d^2}$$

I = Illumination in foot-candles.

$c.p.$ = Candle-power of the unit.

k = Coefficient of reflection of the walls.

d = distance from the unit in feet.

Where several units of the same candle-power are used this formula becomes:

$$I = c.p. \left(\frac{1}{d^2} + \frac{1}{d_1^2} + \frac{1}{d_2^2} + \text{-----} \right) \frac{1}{1-k}$$

$$\text{or, } c.p. = \frac{1}{\left(\frac{1}{d^2} + \frac{1}{d_1^2} + \frac{1}{d_2^2} + \text{-----} \right) \frac{1}{1-k}}$$

where d, d_1, d_2 , etc., equal the distances from the point considered to the various light sources. If the lamps are of different candle-power, the illumination may be determined by combining the illumination from each source as calculated separately. An example of calculation is given under "Arrangement of Lamps."

The above method is not strictly accurate because it does not take account of the angle at which the light from each one of the sources strikes the assumed plane of illumination. If the ray of

light is perpendicular to the plane, the formula $I = \frac{c.p.}{d^2}$ gives cor-

rect values. If a is the angle which the ray of light makes with a line drawn from the light source perpendicular to the assumed plane,

then the formula becomes $I = \frac{c.p. \times \cosine a}{d^2}$. Therefore, by

multiplying the candle-power value of each light source in the direction of the illuminated point by the cosine of each angle a , a more accurate result will be obtained.

It is readily seen that the effect of reflected light from the ceilings is of more importance than that from the floor of a room. The value of k , in the above formula, will vary from 60% to 10%, but for rooms with a fairly light finish 50% may be taken as a good average value.

The amount of illumination will depend on the use to be made of the room. One foot-candle gives sufficient illumination for easy reading, when measured normal to the page, and probably an illumination of .5 foot-candle on a plane 3 feet from the floor forms a sufficient ground illumination. The illumination from sunlight reflected from white clouds is from 20 foot-candles up, while that due to moonlight is in the neighborhood of .03 foot-candles. It is not possible to produce artificially a light equivalent to daylight on account of the

great amount of energy that would be required and the difficulty of obtaining proper diffusion.

The method of calculating the illumination of a room that has just been described is known as the *point-by-point* method and it gives very accurate results if account is taken of the angle at which the light from each source strikes the plane of illumination and if the light distribution curves of the units, and the value of k , have been carefully determined. Under these conditions the calculations become extended and complicated and methods only approximate, but simpler in their application, are being introduced. One method, which gives good results when applied to fairly large interiors, makes the flux of light from the light sources the basis of calculation of the average illumination.

Flux of light is measured in lumens and a *lumen* may be defined as the amount of light which must fall on one square foot of surface in order to produce a uniform illumination of an intensity of one foot-candle. A source of light giving one candle-power in every direction and placed at the center of a sphere of one foot radius would give an illumination of one foot-candle at every point in the surface of the sphere and the total flux of light would be 4π , or 12.57, lumens since the area of the sphere would be 4π , or 12.57, sq. ft. A lamp giving one mean spherical candle-power gives a flux of 12.57 lumens and the total flux of light from any source is obtained by multiplying its mean spherical candle-power by 12.57. In calculating illumination it is customary to determine the illumination on a plane about 30 inches from the floor for desk work, and about 42 inches from the floor for the display of goods on counters. If we determine the total number of lumens falling on this plane and divide this number by the area of the plane, we obtain the average illumination in foot-candles. This of course tells us nothing about the maximum or minimum value of the illumination and such values must be obtained by other methods if they are desired. Reflected light, other than that covered by the distribution curve of the light unit including its reflector, is usually neglected in this method of calculation.

We may assume that in large rooms the light coming from the lamp within an angle of 75 degrees from the vertical reaches the plane of illumination. In smaller rooms this angle should be reduced to about 60 degrees. In order to determine the flux of light within this

angle a Rousseau diagram, which is described later, should be drawn. By the means of this diagram the average candle-power of the light source within the angle assumed may be readily determined and this mean value, multiplied by 12.57, will give the flux of light in lumens. This method of calculation, together with some guides for its rapid application, is described by Messrs. Cravath and Lansingh in the "Transactions of the Illuminating Engineering Society, 1908." The same authorities give the following useful data:

To determine the watts required per square foot of floor area, multiply the intensity of illumination desired by the constants given as follows:

INTENSITY CONSTANTS FOR INCANDESCENT LAMPS

Tungsten lamps rated at 1.25 watts per horizontal candle-power; clear prismatic reflectors, either bowl or concentrating; large room; light ceiling; dark walls; lamps pendant; height from 8 to 15 feet	.25
Same with very light walls	.20
Tungsten lamps rated at 1.25 watts per horizontal candle-power; prismatic bowl reflectors enameled; large room; light ceiling; dark walls; lamps pendant, height from 8 to 15 feet	.29
Same with very light walls	.23
Gem lamps rated at 2.5 watts per horizontal candle-power; clear prismatic reflectors either concentrating or bowl; large room; light ceiling; dark walls; lamps pendant; height from 8 to 15 feet	.55
Same with very light walls	.45
Carbon filament lamps rated at 3.1 watts per horizontal candle-power; clear prismatic reflectors either bowl or concentrating; light ceiling; dark walls; large room; lamps pendant; height from 8 to 15 feet	.65
Same with very light walls	.55
Bare carbon filament lamps rated at 3.1 watts per horizontal candle-power; no reflectors; large room; very light ceiling and walls; height from 10 to 14 feet	.75 to 1.5
Same; small room; medium walls	1.25 to 2.0
Carbon filament lamps rated at 3.1 watts per horizontal candle-power; opal dome or opal cone reflectors; light ceiling; dark walls; large room; lamps pendant; height from 8 to 15 feet	.70
Same with light walls	.60

INTENSITY CONSTANTS FOR ARC LAMPS

5-ampere, enclosed, direct-current arc on 110-volt circuit; clear inner, opal outer globe; no reflector; large room; light ceiling; medium walls; height from 9 to 14 feet	.50
--	-----

Arrangement of Lamps. An arrangement of lamps giving a uniform illumination cannot be well applied to residences on account of the number of units required, and the inartistic effect. We are

limited to chandeliers, side lights, or ceiling lights, in the majority of cases, with table or reading lamps for special illumination.

When ceiling lamps are used and the ceilings are high, some form of reflector or reflector lamp is to be recommended. In any

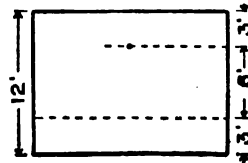
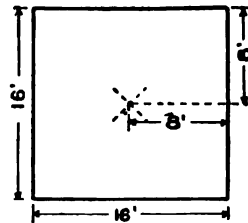


Fig. 53. Diagram Showing Method of Calculating Room Illumination.

case where the coefficient of reflection of the ceilings is less than 40%, it is more economical to use reflectors. When lamps are mounted on chandeliers, the illumination is far from uniform, being a maximum in the neighborhood of the chandelier and a minimum at the corners of the room. By combining chandeliers with side lights it is generally possible to get a satisfactory arrangement of lighting for small or medium-sized rooms.

As a check on the candle-power in lamps required, we have the following:

For brilliant illumination allow one candle-power per two square feet of floor space. In some particular cases, such as ball rooms, this may be increased to one candle-power per square foot.

For general illumination allow one candle-power for four square feet of floor space, and strengthen this illumination with the aid of special lamps as required. The location of lamps and the height of ceilings will modify these figures to some extent.

As an example of the calculation of the illumination of a room with different arrangements of the units of light, assume a room 16 feet square, 12 feet high, and with walls having a coefficient of reflection of 50%. Consider first the illumination on a plane 3 feet above the floor when lighted by a single group of lights mounted at the center of the room 3 feet below the ceiling. If a minimum value of .5 foot-candle is required at the corner of the room, we have the equation (first method outlined):

$$.5 = c. p. \frac{1}{12.8^2} \times \frac{1}{1 - .5}$$

Since $d = \sqrt{8^2 + 8^2 + 6^2} = 12.8$ (see Fig. 53)

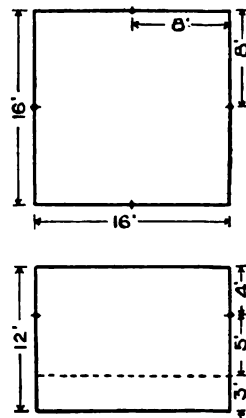


Fig. 54. Diagram for Four 8-c. p. Lamps on Side Wall.

Solving the above for the value of *c. p.*, we have

$$c. p. = \frac{.5}{\frac{1}{164} \times \frac{1}{.5}} = .5 \times 82 = 41$$

Three 16-candle-power lamps would serve this purpose very well.

Determining the illumination directly under the lamp, we have:

$$I = 48 \times \frac{1}{6^2} \times \frac{1}{1-.5} = \frac{48}{36} \times 2 =$$

2.7 foot-candles, or five times the value of the illumination at the corners of the room.

Next consider four 8-candle-power lamps located on the side walls 8 feet above the floor, as shown in Fig. 54. Calculating the illumination at the center of the room on a plane three feet above the floor, we have:

$$I = 8 \left(\frac{1}{89} + \frac{1}{89} + \frac{1}{89} + \frac{1}{89} \right) \frac{1}{1-.5}$$

$$d^2 = 8^2 + 5^2 = 64 + 25 = 89$$

$$I = 8 \times \frac{4}{89} \times 2 = .72 \text{ foot-candles}$$

The illumination at the corner of the room would be:

$$I = 8 \left(\frac{1}{89} + \frac{1}{89} + \frac{1}{345} + \frac{1}{345} \right) \frac{1}{1-.5}$$

$$= 8 \left(\frac{2}{89} + \frac{2}{345} \right) \times 2 = .45 \text{ foot-candles.}$$

In a similar manner the illumination may be calculated for any point in the room, or a series of points may be taken and curves plotted showing the distribution of the light, as well as the areas having the same illumination. Where refined calculations are desired, the distribution curve of the lamp must be used for determining the candle-power in different directions. Fig. 55 shows illumination curves for the Meridian lamp as manufactured by the General Electric Company. This is a form of reflector lamp made in two sizes, 25 or 50 candle-power. Fig. 56 gives the distribution curves for the 50-candle-power unit. Similar incandescent lamps are now being manufactured by other companies.

Table XIV gives desirable data in connection with the use of the Meridian lamp.

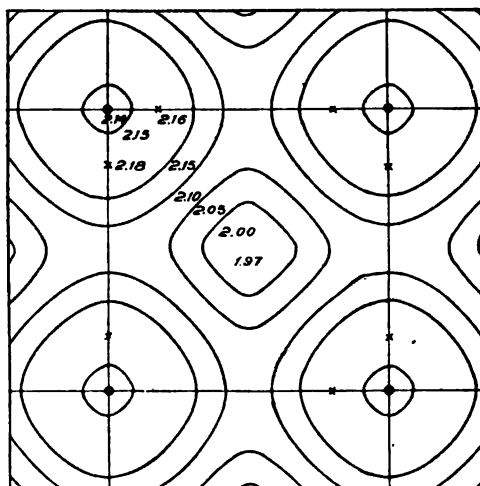


Fig. 55. Illumination Curves for a G. E. Meridian Lamp.

TABLE XIV
Illuminating Data for Meridian Lamps

Class Service	Light Intensity in Foot-candles	No. 1 Lamp (60 Watts)		No. 2 Lamp (120 Watts)		Watts per Sq. Ft. of Area Lighted with either Lamp
		Height of Lamp and Diameter of Uniformly Lighted Area	Distance between Lamps when Two or more are Used	Height of Lamp and Diameter of Uniformly Lighted Area	Distance between Lamps when Two or more are Used	
Desk or Reading Table	3	2.9 feet	4.9 feet	4 feet	7 feet	2.50
	2	3.5 "	6 "	5 "	8.5 "	1.66
	1½	4 "	7 "	5.75 "	9.8 "	1.25
General Lighting	1	5 "	8.5 "	7 "	12 "	0.83
	¾	5.75 "	9.8 "	8.2 "	13.9 "	0.62
	½	7 "	12 "	10 "	11 "	0.41

By means of the Weber, or some other form of portable photometer, curves as plotted from calculations may be readily checked after the lamps are installed. When lamps are to be permanently located, the question of illumination becomes an important one, and it may be desirable to determine, by calculation, the illumination curves for each room before installing the lamps. This applies to the lighting of large interiors more particularly than to residence lighting. The point-by-point method of calculation is used for

very accurate work when the system of illumination admits of this method. Other methods are often simpler and sufficiently accurate for practical work.

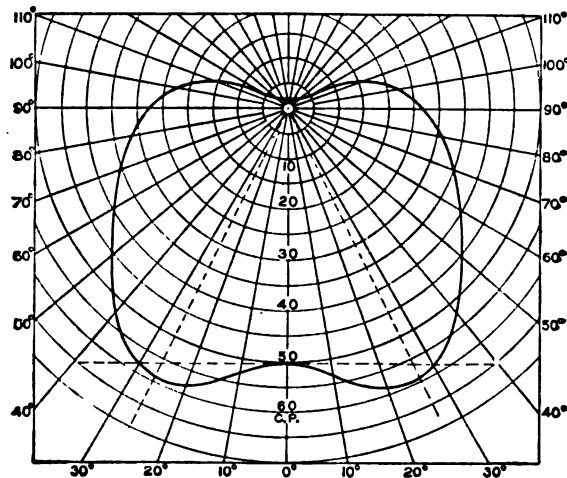


Fig. 56. Distribution Curve for a G. E. 50-c. p. Meridian Lamp.

Dr. Louis Bell gives the following in connection with residence lighting:

TABLE XV
Residence Lighting Data

Room	8 C. P.	16 C. P.	32 C. P.	Sq. Ft. Per C. P.	Remarks
Hall, 15' × 20'	8			4.7	
Library, 20' × 20'	12		1	3.1	8-c.p. reflector lamps
Reception room, 15' × 15' ..	4			7.0	
Music room, 20' × 25'	12		2	3.0	8 reflector lamps 32-c.p. with reflectors
Dining room, 15' × 20'	14			2.7	
Billiard room, 15' × 20'			4	2.3	
Porch			1		
Bedrooms (6), 15' × 15'		14		7.0	
Dressing rooms (2), 10' × 15' ..		4		4.7	
Servants' rooms (3), 10' × 15' ..		3		9.4	
Bathrooms (3), 8' × 10'		3		5.0	
Kitchen, 15' × 15' }					
Pantry, 10' × 15' }		3			
Halls }					
Cellar }	10	3			Reflector lamps
Closets (4)	4				
Total	64	30	8		

LIGHTING OF PUBLIC HALLS, OFFICES, ETC.

Lighting of public halls and other large interiors differs from the illumination of residences in that there is usually less reflected light, and, again, the distance of the light sources from the plane of illumination is generally greater if an artistic arrangement of the lights is to be brought about. This in turn reduces the direct illumination. The primary object is, however, as in residence lighting, to produce a fairly uniform ground illumination and to superimpose a stronger illumination where necessary. An illumination of .5 foot-candle for the ground illumination may be taken as a minimum.

In the lighting of large rooms it is permissible to use larger light units, such as arc lamps and high candle-power Nernst or incandescent units, while for factory lighting and drafting rooms, where the color of the light is not so essential, the Cooper-Hewitt lamp is being introduced. High candle-power reflector lamps, such as the tungsten lamp, are being used to a large extent for offices and drafting rooms.

The choice of the type of lamp depends on the nature of the work. Where the light must be steady, incandescent or Nernst lamps are to be preferred to the arc or vapor lamps, though the latter are often the more efficient. When arcs are used, they must be carefully shaded so as to diffuse the light, doing away with the strong shadows due to portions of the lamp mechanism, and to reduce the intrinsic brightness. Such shading will be taken up under the heading "Shades and Reflectors." Arcs are sometimes preferable to incandescent lamps when colored objects are to be illuminated, as in stores and display windows.

In locating lamps for this class of lighting, much depends on the nature of the building and on the degree of economy to be observed. For preliminary determination of the location of groups, or the illumination when certain arrangement of the units is assumed, the principles outlined under "Residence Lighting" may be applied. It has been found that actual measurements show results approximating closely such calculated values.

When arcs are used they should be placed fairly high, twenty to twenty-five feet when used for general illumination and the ceilings are high. They should be supplied with reflectors so as to utilize the light ordinarily thrown upwards. When used for drafting-room

work, they should be suspended from twelve to fifteen feet above the floor, and special care must be taken to diffuse the light.

Incandescent lamps may be arranged in groups, either as side lights or mounted on chandeliers, or they may be arranged as a frieze running around the room a few feet below the ceiling. The last named arrangement of lights is one that may be made artistic, but it is uneconomical and when used should serve for the ground illumination only. Reflector lights may be used for this style of work and the lights may be entirely concealed from view, the reflecting property of the walls being utilized for distributing the light where needed.

Ceiling lights should preferably be supplied with reflectors, especially when the ceilings are high.

Indirect lighting is employed to some extent. By indirect lighting we mean a system of illumination in which the light sources are concealed and the light from them is reflected to the room by the walls, or ceilings, or other surfaces; or in which the light sources are placed above a diffusing panel. In the latter case the diffusing plate appears to be the source of light. In some cases the walls themselves are shaped and constructed so as to form the reflectors for the light units (cove lighting), but in others all of the reflecting surfaces, except the side walls and ceiling, are made portions of the lamp fixtures.

Tables XVI and XVII give data on arc and mercury-vapor lamps for lighting large rooms. Table XVII refers to arc lights as actually installed.

TABLE XVI

Cooper-Hewitt Lamps

SERVICE	HEIGHT OF LAMP	C. P. OF UNIT	AV. AREA PER LAMP IN SQUARE FEET
Foundry	10-15 ft.	300	900
"	20-25 "	700	2250
Machine shop	10-15 "	300	500
Erecting shop	20-30 "	700	1250
Drafting room	15 "	300	300
" "	20 "	700	400
Offices	10-15 "	300	400
"	20-25 "	700	750
Ordinary labor	10-15 "	300	1100
" "	20-25 "	700	2750

TABLE XVII
Lighting Data for Arc Lamps

PLACE LIGHTED	CLOTHING STORE	WEAVE ROOM	ERECTING ROOM	MACHINE SHOP	DRAFTING ROOM	DRAFTING ROOM	SHIP SHED	CATALOGING DEPT.	JEWELRY STORE
No. of sq. ft. place lighted	4000	14400	281600	42250	6275	5650	69000	4136	4000
No. lamps used	12	50	200	42	27	24	50	17	6
Circuit	A. C. Mult.	D. C. Mult.	D. C. Mult.	D. C. Mult.	A. C. Series	D. C. Mult.	D. C. Mult.	D. C. Mult.	D. C. Mult.
Cycles	60	110	130	120	60	120	220	110	110
Volts line	104	110	130	120	7.5	4	6	4½	5
Amperes	6	31	6.2	6.2	72	80	80	80	80
Volts at arc	72	75	80	80	.86				
Power factor of lamp	.69								
Watts per lamp	430	357	744	744	400	480	660	495	550
Watts per sq. ft. (term.)	1.29	1.24	.53	.74	2.11	2.02	.478	2.03	.825
Kw. at term. (whole installation)	5.16	17.8	148.8	31.25	13.22	11.52	33	8.42	3.3
Kw. at arc (whole installation)	4.62	12.28	99.2	20.8	12.42	7.08	24	6.12	2.4
Sq. ft. lighted per lamp	333	288	1408	1006	232	237	1380	243	667
Sq. ft. lighted per amp	55.6	88.6	227	162	31	59.2	230	54.1	133.5
Enclosing globe	Opal.	Opal.	Opal.	Opal.	Opal.	Opal.	Opal.	Opal.	Opal.
Height and style of ceiling	12' white steel	Saw Toothed	Trussed	Trussed	12' White	Trussed	160'	13' 9"	16' 10'
Reflector system used	Concentric	Adjust.	9' Mirror	9' Mirror	Concentric	16 Adj. Diff.	Trussed	Maroon	White
Height of arc from floor	Diffuser 9' 6"	Diffuser 12' to 15'	46'	47'	Diffuser 9'	8 Con. Diff. 15'	12" Mirror 150'	Concentric Diffuser 10' 7"	Concentric Diffuser 13' 2"
Distance between lamps	14' to 18'	24'	32' to 38'	30' 9"	15'	12' to 25'	17' to 20'	14' to 18'	16' to 25'



WESTINGHOUSE-D. C.-MULTIPLE-ARC LAMPS IN A LUNCH ROOM

Measurements taken in well-lighted rooms having a floor space of from 1,000 to 5,000 square feet show an average of 3 to 3.5 square feet per candle-power. About 2.5 square feet per candle-power should be allowed when brilliant lighting is required or the ceilings are very high, while 3.75 square feet per candle-power will give good illumination when lights are well distributed and there is considerable reflected light.

In factory and drafting room lighting, the lamps must be arranged to give a strong light where most needed, and located to prevent such shadows as would interfere with the work.

STREET LIGHTING

In studying the lighting of streets and parks, we find that, except in special cases, such as narrow streets and high buildings, there is no reflected light which aids the illumination aside from that due to special shades or reflectors on the lamp itself. Such reflectors are necessary if the light ordinarily thrown above the horizontal plane is to be utilized.

In calculating the illumination due to any type of lamp at a given point it is necessary to know the distribution curve of the lamp used and the distance to the point illuminated. The approximate illumination of a plane normal to the rays of light is given by the formula,

$$I = \frac{c.p.}{h^2 + d^2}$$

when I = illumination in foot-candles.

$c.p.$ = candle-power of the unit, determined from the distribution curve of the lamp.

h = distance the lamp is mounted above the ground, in feet, and d = distance from the base of the pole supporting the lamp to the point where the illumination is being considered, Fig. 57.

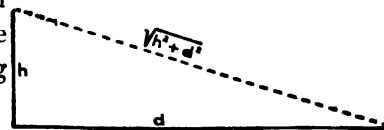


Fig. 57. Street Light Illumination Diagram.

While this will give the illumination in foot-candles, the nature of the lighting cannot be decided from this alone, but the total amount of light must also be considered. Thus, a street lighted with powerful units and giving a minimum

illumination of .05 foot-candles would be considered better illuminated than one having smaller units so distributed as to give the same minimum value.

Since a uniform distribution of light is desirable, for economic reasons, the ideal distribution curve of a lamp for street lighting would be a curve which shows a low value of candle-power thrown directly downward, but with the candle-power increasing as we approach the horizontal. Such an ideal distribution curve is shown in Fig. 58.

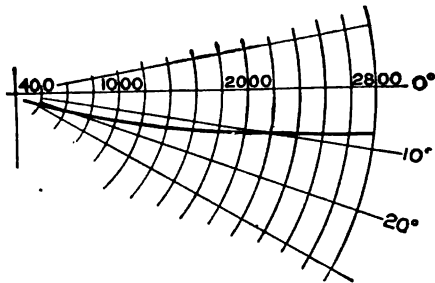


Fig. 58. Ideal Distribution Curve for a Street Light.

Actual distribution curves taken from commercial arc lamps are given in Fig. 59, in which

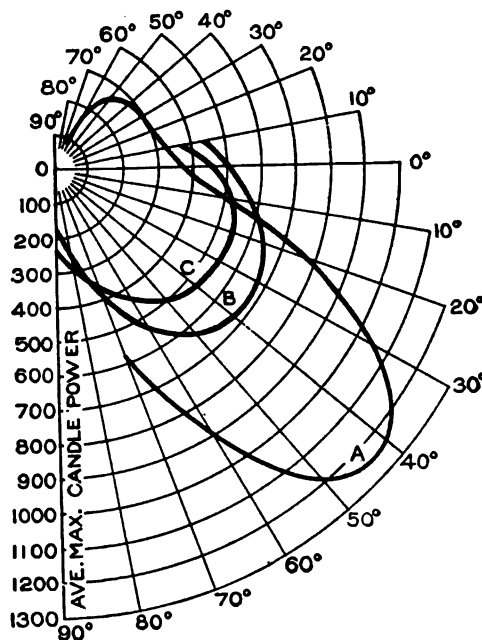


Fig. 59. Distribution Curves for Commercial Arc Lamps Used in Street Lighting.

Curve A shows distribution curve for a 9.6-ampere, open, direct-current arc.

Curve B shows distribution curve for a 6.6-ampere, D.C. enclosed arc.

Curve C shows distribution curve for a 7.5-ampere, A.C. enclosed arc.

Globes used with B and C are opal inner globes, clear outer globes.

Globes used with A are clear outer globes.

A street reflector was used with the enclosed arcs.

Typical curves for flaming and luminous arc lamps are shown in Figs. 40, 43, and 44.

A series of curves known as *illumination curves* may be readily calculated showing the illumination in foot-candles at given distance

from the foot of the pole supporting the lamp. Illumination curves corresponding to the distribution curves in Fig. 59 are given in Fig. 60 where A' , B' , and C' correspond to A , B , and C in Fig. 59. These curves correspond to actual readings taken with commercial lamps. Similar curves for incandescent lamps fitted with suitable reflectors are shown in Fig. 61. A value of .03 foot-candles is about the min-

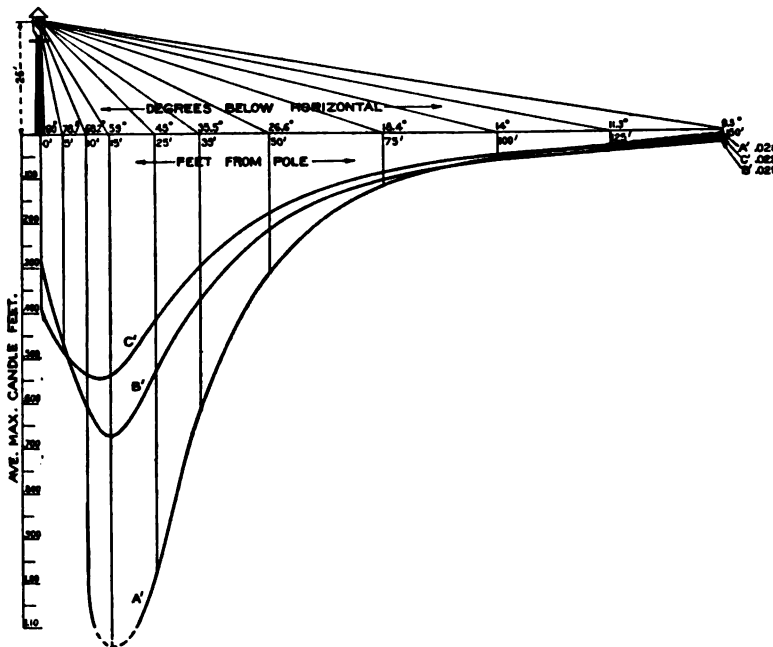


Fig. 60. Illumination Curves Drawn to Data given in Fig. 59.

imum for street lighting. Open arcs should be placed at least 25 feet above the ground; 30 to 40 feet is better, especially if the space to be illuminated is quite open. With enclosed arcs it is often advantageous to place them as low as 18 to 20 feet from the ground. Table XVIII gives the distance between lights for different types of arcs for fair illumination.

In considering the type of arc light to be used we must turn to the illumination curves as shown in Fig. 60. These curves show that the illumination from a direct-current open arc in its present form is superior to that from a direct-current enclosed arc, taking the

TABLE XVIII

KIND OF LIGHT	DISTANCE BETWEEN LIGHTS	LIGHTS PER MILE
6.6-ampere enclosed D.C. arc	340 feet	15
9.6-ampere open D.C. arc	315 "	17
6.6-ampere enclosed A.C. arc	275 "	19
6.6-ampere open D.C. arc	260 "	20

same amount of power, in the vicinity of the pole; but at a distance of 100 feet, the illumination from the enclosed arc is better. This

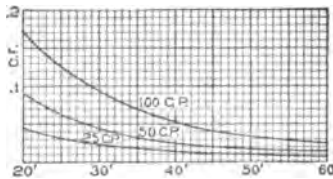


Fig. 61. Illumination Curves for Street Incandescent Lamps.

illumination is still more effective on account of the absence of such strong light as is given by the open arc near the pole. The pupil of the eye adjusts itself to correspond to the brightest light in the field of vision, and we are unable to see as well in the dimly-lighted section as when the maximum intensity is less. The characteristics

of the open and enclosed direct-current arc lamps are as follows:

The mean spherical candle-power and energy required at the arc are variable with the open arc.

Fluctuations of light are marked, due to wandering of the arc, flickering due to the wind and lack of uniformity of the carbons.

Dense shadows are cast by the side rods and the lower carbon, while the light is objectionably strong in the vicinity of the pole.

With the enclosed arc the mean spherical candle-power and the watts consumed at the arc are fairly constant.

No shadows are cast by the lamps, and the illumination is not subject to such wide variations. The enclosed arc is much superior to the open arc using the same amount of energy. This applies to the open arc as it is now used. With proper reflection and diffusion of the light such as might be accomplished by extensive or special shading, we ought to be able to get as good distribution from the open arc with a greater total amount of illumination.

In comparing the direct-current with the alternating-current enclosed arc, we see that the direct-current arc gives slightly more light than the alternating lamp, but this may be more than counterbalanced by the better distribution of light from the alternating-current lamp. The selection of A.C. or D.C. enclosed lamps will usually depend on other conditions, such as method of distribution of power, efficiency of plant, etc.

TABLE XIX
Street-Lamp Data

LAMP	AMPERES	APPROX. WATTS AT LAMP TERMINALS	APPROX. VALUE OF X AS PROPOSED
D. C. Series, open arc, clear globe	{ 6.6 9.6	330 450	3.5 4
D. C. Series, enclosed, clear outer globe	{ 5.0 6.6	370 480	3.5 4
Opalescent inner globe, street reflectors	{ 5.5 6.6	345 430	3 3.5
A. C. Series as above	{ 7.5	480	4
D. C. Series "Magnetite"	4.0	310	5.5

The question of street lighting has been given considerable attention by the National Electric Light Association and this society recommends the following form of specification for street lights:

1. Under ordinary conditions of street lighting, with lamps spaced 200 to 600 feet apart, specifications for street lamps should define the mean illumination thrown by the individual lamp, in position in the street, as measured at the height of the observer's eye and perpendicular to the rays, at some point not less than 200 feet nor more than 300 feet distant, along a level street, from a position immediately below the lamp, with all extraneous light screened off and with no reflection from surrounding objects not forming part of the lamp equipment.

2. When using smaller units of light, such as series incandescent lamps spaced shorter distances apart, a correspondingly shorter distance from the lamp should be chosen in measuring the illumination.

3. The lamp contracted for should give a mean normal illumination at the test point (selected as in Sections 1 and 2) not less than the illumination given by the stationary standard incandescent lamp of 16 candle-power at $1/X$ of the distance. The said standard incandescent lamp should be a standardized seasoned lamp having a determined candle-power in a fixed direction.

4. When the lamp tested fluctuates in intensity, a number of observations of the maximum normal illumination should be made at a distance of not less than 200 feet horizontally from beneath the lamp, and the average of these measurements should be taken as the average maximum illumination. A similar number of observations of the minimum normal illumination should be made, the average of which should be taken as the average minimum illumination. The arithmetical mean of the said average maximum and minimum illuminations should be taken as the mean normal illumination called for in Section 1.

5. A reasonable number of the lamps covered by the contract should be tested.

6. For measuring the mean normal illumination of a lamp, comparison with the standard incandescent lamp may be made either with a suitable portable

photometer or with a reading distance instrument, such as the so-called *luminometer*.

7. The unobstructed mean normal illumination must not be less at shorter distances than at the point of test.

8. An approximate value of the mean normal illuminations thrown by street lamps of standard manufacture, at horizontal distances within the 200–300-foot range, hung approximately 20 feet above the observer's eye, may be determined from Table XIX.

Series incandescent lamps are used considerably for lighting the streets in residence sections of cities or where shade trees make it impracticable to use arcs. These vary in candle-power from 16 to 50 or even higher, and are usually constructed so as to take from two to four amperes. The best arrangement of these is to mount them on brackets a few feet from the curb, with alternate lamps on opposite sides of the street. The distance between the lamps depends on their power. 50 candle-power lamps spaced 100 feet between lamps, give a minimum illumination of .02 foot-candle. 25 candle-power lamps spaced 75 feet between lamps will serve where economy is necessary.

TABLE XX

	PER CENT
Clear glass	10
Alabaster glass	15
Opaline glass	20–40
Ground glass	25–30
Opal glass	25–60
Milky glass	30–60
Ground glass	24.4
Opal glass	32.2
Opaline glass	23

SHADES AND REFLECTORS

Lamps, as ordinarily constructed, do not always give a suitable distribution of light, while the intrinsic brightness is often too high for interior lighting. Shades are intended to modify the intensity of the light, while reflectors are used for the purpose of changing its direction. Frequently the two are combined in various ways. Shades are also used for decorative purposes, but, if possible, these should be of such a nature as to aid illumination rather than to reduce its efficiency.

A considerable amount of light is absorbed by the material used for the construction of shades. Table XX shows the approximate amount absorbed by some materials.

Of the great number of styles of shades and reflectors in use, only a few of the more important will be considered here.

Frosted Globes. One of the simplest methods of shading incandescent lamps is by the use of frosted bulbs. These serve to reduce the intrinsic brightness of the lamp, and should be freely used for residence lighting when separate shades are not installed. Frosted globes are also used in connection with reflectors for the purpose of diffusing the reflected light. The *McCreary shade* as shown in Fig. 62, is an example of such a combined shade and reflector. Fig. 63 shows the distribution curve taken from an incandescent lamp using a McCreary shade. Fig. 64 shows the distribution of light from a conical shade. Fig. 56 shows the distribution of light brought about by means of a spiral filament and a reflector as used in the Meridian lamp.

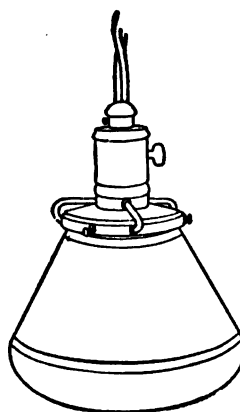


Fig. 62. McCreary Shade.

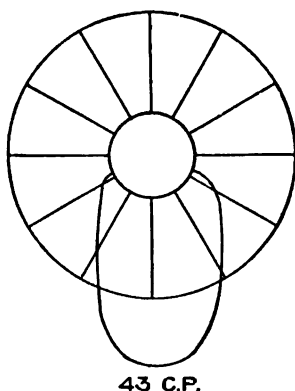


Fig. 63. Distribution Curve for Incandescent Lamp Provided with McCreary Shade.

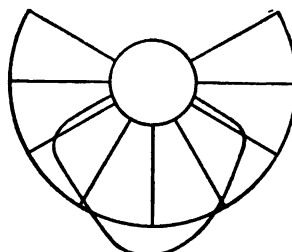


Fig. 64. Distribution Curve for Incandescent Lamp Provided with Conical Shade.

Holophane Globes. These are made for both reflecting and diffusing the light, and they can be made to bring about almost any desired distribution with but a small amount of absorption of light. These consist of shades of clear glass having horizontal grooves forming surfaces which change the direction of light by refraction or total reflection as is necessary. The diffusion of light is effected by means of deep, rounded, vertical grooves on the interior surface of the globe. While these globes are of clear glass and absorb an amount of light corresponding to clear glass, the light is so well diffused that the filament of the lamp cannot be seen, and the globe appears as if



Fig. 65. Enclosed Arc Lamp Fitted with Shade and Concentric Diffuser.

made of some semi-transparent material. The holophane glassware is made in a large variety of artistic designs and for all types of incandescent lamps. By the proper selection of a reflector the distribution of the light of the unit used may be made that which is best suited to the particular case of lighting in hand. Figs. 9, 13, 14, 15, 16, 17, and 18 give some idea of what can be accomplished by these shades.

Fig. 65 shows an enclosed arc lamp fitted with a shade and a concentric *diffuser*. The effect of this combination is best shown in Fig. 66. Fig. 67 shows the change in the illumination curve produced by such shading. Inverted arcs have some application where

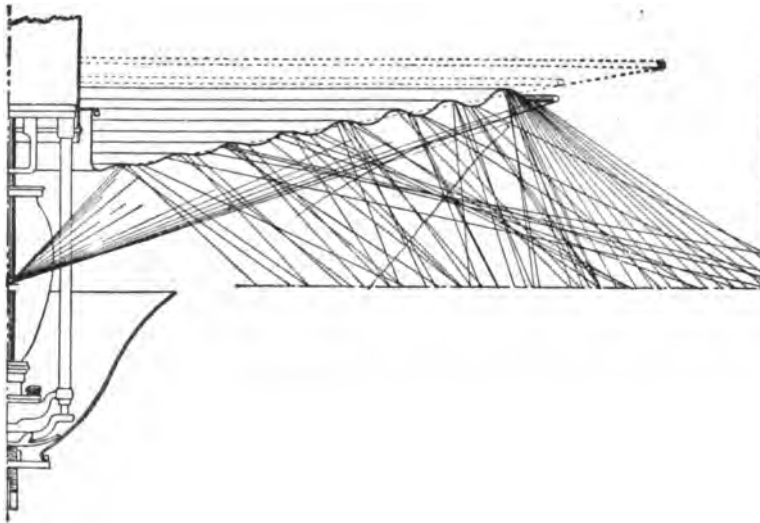


Fig. 66. Diagram Showing Effect of the Concentric Diffuser.

the light may be readily reflected and diffused as in lighting large rooms with light finish. Reflectors of this general type are now being manufactured in such a form that they may be built in and become part of the ceiling of the room to be illuminated.

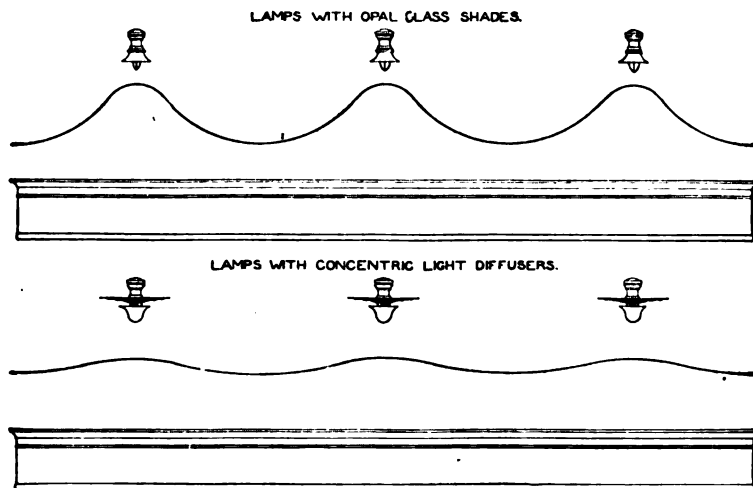


Fig. 67. Illumination Curves for Lamps with and without Light Diffusers.

Opal Enclosing Globes. The use of opal enclosing globes is recommended for arc lamps used for street lighting for the reason that they change the distribution of the light so that it covers a greater area, and the light is so diffused as to obliterate shadows in the vicinity of the lamp. Table XXI gives the efficiency of different globe combinations for street lighting assuming the opal inner and the clear outer globes as 100%.

TABLE XXI

Opal enclosing and clear outer.....				100	per cent
Clear	"	"	clear	91.2	"
"	"	"	opal	85.1	"
Opal	"	"	opal	82.7	"

PHOTOMETRY

Photometry is the art of comparing the illuminating properties of light sources, and forms one branch of scientific measurement. Its use in electric illumination is to determine the relative values of different types of lamps as sources of illumination, together with their efficiency; also by means of the principles of photometry, we are able to study the distribution of illumination for any given arrangement of light sources.

LIGHT STANDARDS

Inasmuch as sources of light are compared with one another in photometry, we must have some standard, or unit, to which all light sources are reduced. This unit is usually the candle-power and the rating of most lamps is given in candle-power.

While the candle-power remains the unit and is based on the standard English candle, other light standards have been introduced and are much more desirable.

The English Candle. The English candle is made of spermaceti extracted from crude sperm oil, with the addition of a small quantity of beeswax to reduce the brittleness. Its length is ten inches, and its diameter .9 inch at the bottom and .8 inch at the top, and its weight is one-sixth of a pound. Great care is taken in the preparation of the wick and spermaceti. This candle burns with a normal height of flame of 45 millimeters and consumes 120 grains per hour when

burning in dry air at normal atmospheric pressure. Under these conditions, the light given by a single candle is one candle-power.

When used for measurements, the candle should be allowed to burn at least fifteen minutes before taking any readings. At the end of this period the wick should be trimmed, if necessary, and when the flame height reaches 45 millimeters, readings can be taken. The candle should not require trimming when the proper height of flame has been reached. It is best to weigh the amount of material consumed by balancing the candle on a properly arranged balance when the first reading is taken, and again balancing at the end of a suitable period—ten to fifteen minutes. The candle-power of the unit is then, practically, directly proportional to the amount of the material consumed.

The objections to the candle as a unit are that it burns with an open flame which is subject to variation in height and to the effect of air currents. The color of the light is not satisfactory, being too rich in the red rays, and the composition of the spermaceti is more or less uncertain.

The German Candle is made of very pure paraffine, burns with a normal flame height of 50 millimeters, and is subject to the same disadvantages as the English candle. It may be necessary to trim the wick to keep the flame height at 50 millimeters. The light given is a trifle greater than for the spermaceti candle.

The Carcel Lamp is built according to very careful specifications and burns colza (rape seed) oil. It has been used to a large extent in France, but its present application is limited.

The Pentane Lamp is a specially constructed lamp burning pentane, prepared by the distillation of gasoline between narrow limits of temperature. This standard is not extensively used.

The Amyl Acetate Lamp. This lamp, known also as the *Hefner lamp*, is at present the most desirable standard. It is a lamp built to very careful specifications, especially with regard to the dimension of the wick tube. It burns pure amyl acetate and the flame height should be 40 millimeters. This flame height must be very carefully adjusted by means of gauges furnished with the lamp. Amyl acetate is a colorless hydrocarbon prepared from the distillation of amyl alcohol obtained from fusil oil, with a mixture of acetic and sulphuric acids, or by distillation of a mixture of amyl acetate, sulphuric acid,

and potassium acetate. It has a definite composition, and must be pure for this use.

The most serious disadvantage of this standard is the color of the light, inasmuch as it has a decidedly red tinge and is not readily compared with whiter lights. Its value is affected somewhat by the moisture in the air and the atmospheric pressure, but it excels all other standards in that it is quite readily reproduced.

Table XXII gives the value of the candle-power units of different laboratories in terms of the unit of the Bureau of Standards and also the values of the units of the Carcel and Vernon-Harcourt in terms of the Hefner, as accepted by the International Photometric Commission.

TABLE XXII
Photometric Units

Bureau of Standards Unit, United States	1.000		
Reichsanstalt Unit, Germany	0.998 $\times$ 0.88		
National Physical Laboratory Unit, England	0.984		
Laboratoire Central Unit, France	0.982		
	CARCEL	HEFNER	VERNON-HARCOURT
Carcel	1.00	10.75	0.980
Hefner	0.0930	1.00	0.0915
Vernon-Harcourt (pentane)	1.020	10.95	1.0

The above values are at a barometric pressure of 760 mm. of mercury and a humidity for the Carcel and Vernon-Harcourt standards of 10.0 liters of water per cubic meter of dry air. The humidity for the Hefner unit is 8.8 liters of water to one cubic meter of dry air.

Working Standards. Incandescent Lamp. The units just described, together with some others, form reference standards, but an incandescent lamp is generally used as the working standard in all photometers. An incandescent lamp, when used for this work, should be burned for about two hundred hours, or until it has reached the point in the life curve where its value is constant, and it should then be checked by means of some standard when in a given position and at a fixed voltage. It then serves as an admirable working standard if the applied voltage is carefully regulated. Two such lamps should always be used—the one to serve as a check on the other; the checking lamp to be used for very short intervals only.

PHOTOMETERS

Two light sources are compared by means of a photometer which, in one of its simplest forms, consists of what is known as a *Bunsen screen* mounted on a carriage between the two lights being compared, with its plane at right angles to a line passing through the light sources, and arranged with mirrors or prisms so that both sides of the screen may be observed at once. The Bunsen screen consists of a disk of paper with a portion of either the center, or a section around the center, treated with paraffine so as to render it translucent. If the light falling on one side of this screen is in excess, the translucent spot will appear dark on that side of the screen and light on the opposite side.

Care must be taken to see that the two sides of the screen are exactly alike, otherwise there will be an error introduced in using the screens. It is well to reverse the screen and check readings whenever a new lot of lamps are to be tested. When the light falling on the two sides of the screen is the same, the transparent spot disappears. The values of the two light sources are then directly proportional to the square of their distances from the screen.

As an example, consider a 16 candle-power lamp being compared with a standard candle on a photometer with a 300-centimeter bar. Say the translucent spot disappears when the screen is distant 60 centimeters from the standard candle, we then have the proportion,

$$x : 1 = (240)^2 : (60)^2 = 16 : 1,$$

showing that the lamp gives 16 candle-power.

The above law is known as the law of inverse squares, and holds true only when the dimensions of the light sources are small compared with the distance between them, and when there are no reflecting surfaces present as when the readings are taken in a dark room.

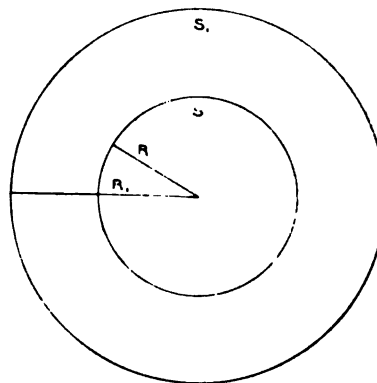


Fig. 68. Proof of the Law of Inverse Squares by the Method of Concentric Spheres.

The proof that the light varies inversely with the square of distance from the source is as follows:

Consider two spherical surfaces, Fig. 68, illuminated by a source of light at the center. The same quantity of light falls on both surfaces.

$$\text{Area of } S = 4\pi R^2 \text{ sq. ft. } (R \text{ is in feet.})$$

$$\text{Area of } S_1 = 4\pi R_1^2 \text{ sq. ft.}$$

Let Q = total quantity of light and q = light falling on unit surface. Then,

$$q = \frac{Q}{4\pi R^2}$$

$$q_1 = \frac{Q}{4\pi R_1^2}$$

$$q : q_1 = \frac{Q}{4\pi R^2} : \frac{Q}{4\pi R_1^2}$$

$$= 4\pi R_1^2 : 4\pi R^2$$

$$\frac{q}{q_1} = \frac{R_1^2}{R^2}$$

Fig. 69 shows the relation in another way. The area of C , distant two units from the source of light A , is four times that of B which is distant one unit.

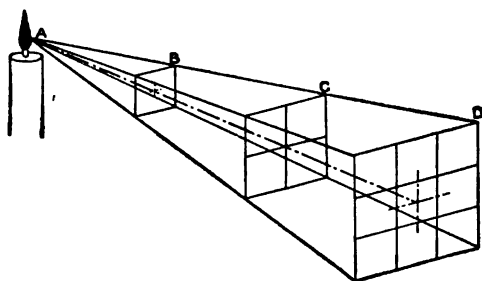


Fig. 69. Proof of the Law of Inverse Squares by Method of Screen Shadow.

The Lummer-Brodhun Photometer. In addition to the Bunsen screen described, there are several other forms of photometers, the most important of which is the Lummer-Brodhun. The essential

feature of this instrument is the optical train which serves to bring into contrast the portions of the screen illuminated by the two sources of light. Referring to Fig. 70 the screen S is an opaque screen which

reflects the light falling upon it from L , to the mirror M , when it is again reflected to the pair of glass prisms A, B . The surfaces sr are ground to fit perfectly and any light falling on this surface will pass through the prisms. Light falling on the surface ar or bs will be reflected as shown by the arrows. We see then that the light from L , which falls on ar and bs , is reflected to the eye piece or telescope T , while that falling on sr is transmitted to and absorbed by the black interior of the containing box. Likewise, the light from the screen

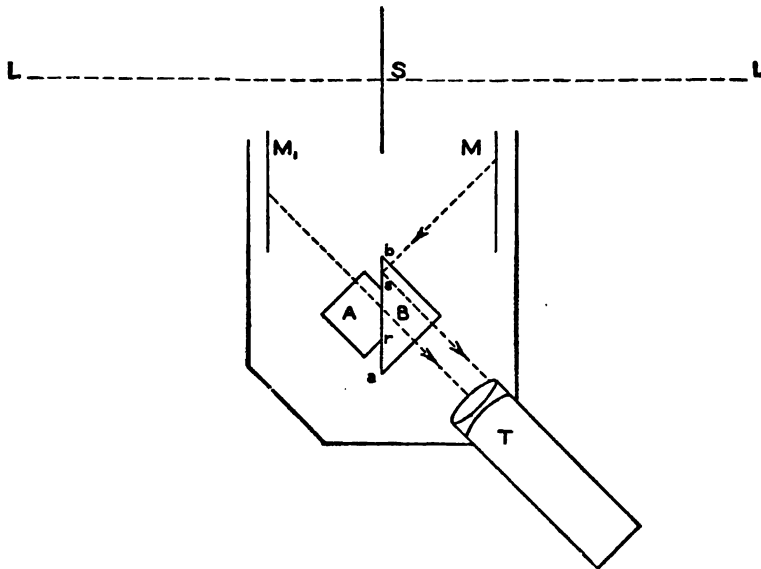


Fig. 70. Diagram of Lummer-Brodhun Screen.

L_1 is reflected by the screen M_1 to the pair of prisms A, B . The rays falling on the surface sr pass through to the telescope T , while the rays falling on ar and bs are reflected and absorbed by the black lining of the case. The field of light, as then viewed through the telescope, appears as a disk of light produced by the screen L_1 , surrounded by an annular ring of light produced by L . When the illumination on the two sides of the screen is the same, the disk and ring appear alike and the dividing circle disappears.

In using this screen, it is mounted the same as the Bunsen screen and readings are taken in the same manner. The screen and prisms are arranged so that they can be reversed readily and two readings

should always be taken to compensate for any inequalities in the sides of the screen and the reflecting surfaces, a mean of the two readings

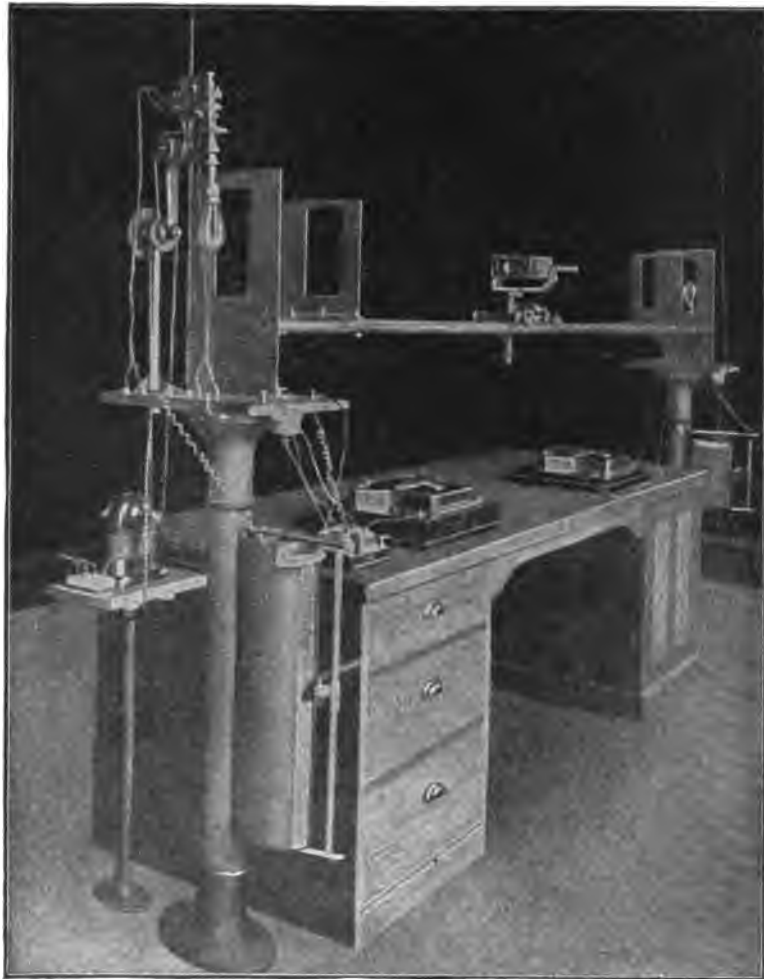
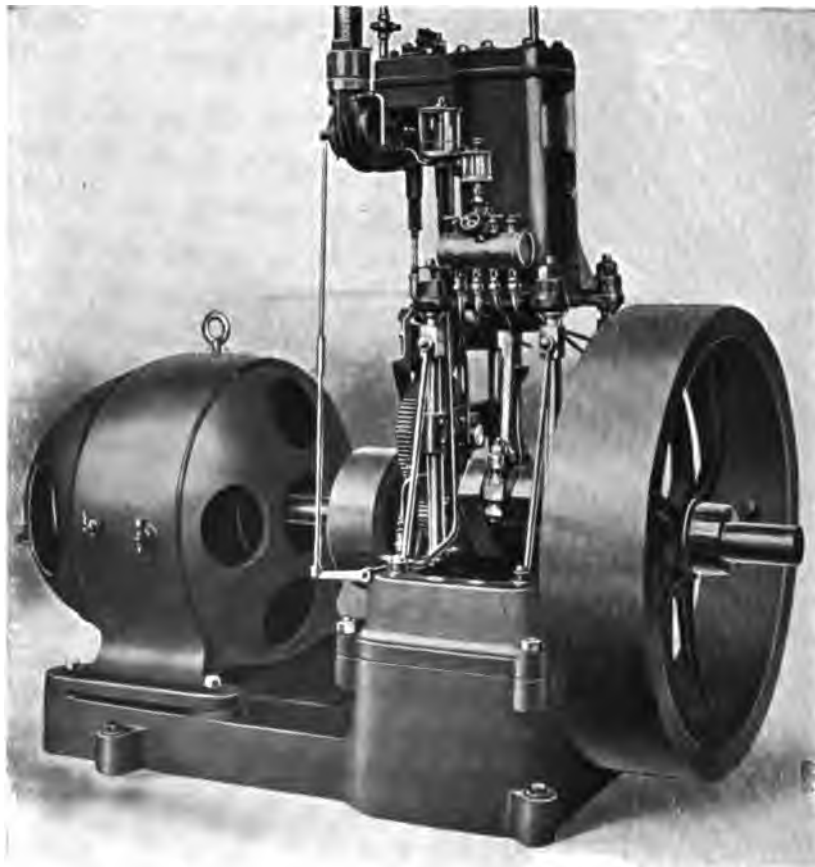


Fig. 71. Complete Photometer with Lummer-Brodhun Screen.

serving as the true reading. This form of screen is used when especially accurate comparisons are required.

Fig. 71 shows a complete photometer with a Lummer-Brodhun screen, while Fig. 72 shows a Bunsen screen and sight box. In Fig. 71, the lamps are shaded by means of curtains so as to leave only a



5 KILOWATT, 80 LIGHT.
Secor Oil-Electric Generating Plant.

small opening toward the screen. If the lights are properly screened photometric measurements may be made in rooms having light-colored walls.

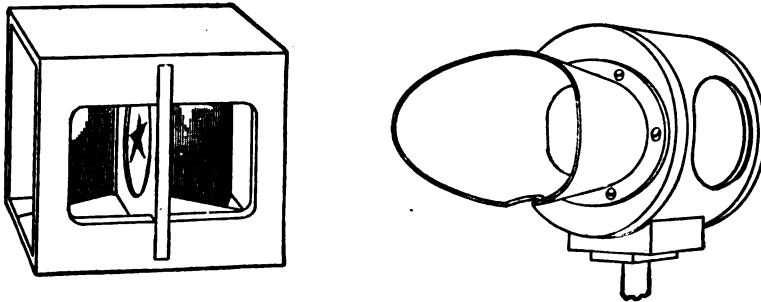


Fig. 72. Bunsen Screen and Sight Box.

The Weber Photometer. As an example of a portable type of photometer, we have the Weber. This photometer, shown in Fig. 73, is very compact and is especially adapted to measuring intensity of illumination as well as the value of light sources; it may be used for exploring the illumination of rooms or the lighting of streets.

This apparatus consists of a tube *A*, Fig. 74, which is mounted horizontally and contains a circular, opal glass plate *f*, which is movable by means of a rack and pinion. To this screen is attached an index finger which moves over a scale attached to the outside of the tube. A lamp *L*, burning benzine, is mounted at the end of this tube. The benzine used should be as pure as possible, and the flame height should be

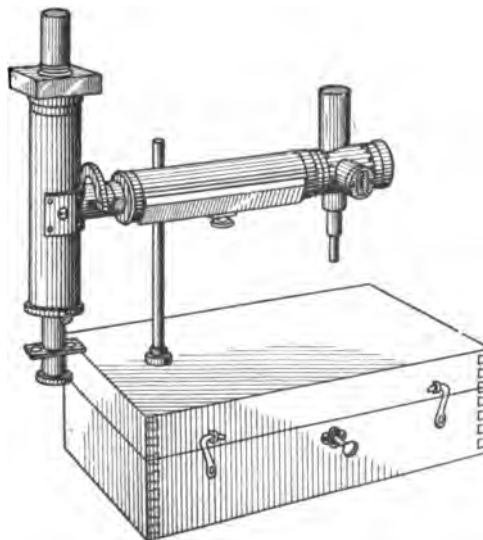


Fig. 73. Weber Portable Photometer.

carefully adjusted to 20 mm. when taking readings. At right angles to the tube *A* is mounted the tube *B* which contains an eye piece at *O*, a Lummer-Brodhun contrast prism at *p*, and a support for opal or colored glass plates at *g*.

Operation. The tube *B* is turned toward the source of light to be measured, the distance from the light to the screen at *g* being noted. The light from this source is diffused by the screen at *g*, while that from the standard is diffused by the screen *f*. By moving the screen *f*, the light falling on either side of the prism *p* can be equalized. The value of the unknown source can be determined from the reading of the screen *f*, the photometer having previously been calibrated by

means of a standard lamp in place of the one to be measured. The calibration may be plotted in the form of a curve or it may be denoted by a constant *C*, when we have the formula,

$$I' = C \frac{L^2}{f^2}$$

C corresponds to a particular plate at *g*, *l* = distance of screen *f* from the benzine lamp, and *L* = distance from the screen *g* to the light source being measured. Screens of different densities may be used at *g*, depending on

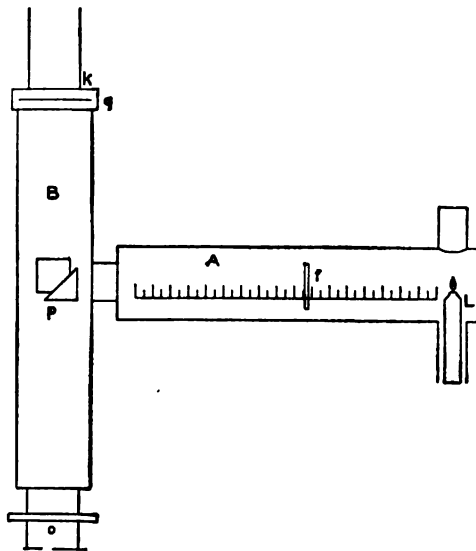


Fig. 74. Diagram of Weher Photometer.

the strength of the light source.

When used for measuring illumination, a white screen is used in connection with this photometer. The screen is mounted in front of the opening at *g*, and turned so that it is illuminated by the source being considered. Readings of the screen *f* are taken as before. A calibration curve is plotted for the instrument, using a known light source at a known distance from the white screen when the instrument is mounted in a dark room.

Portable Photometers. There is a large variety of portable photometers available and giving more or less satisfactory results. An instrument especially designed with a view to portability and to overcoming some of the defects of instruments already on the market has recently been introduced. The instrument referred to is called a *Universal photometer* but it is more commonly known as the *Sharp-Millar photometer* from the names of its inventors. Views of this instrument are shown in Figs. 75 and 76. It is adapted to the measurement of the intensity of light sources as well as to the illumination at any point, as is the Weber photometer. The photometer screen or photometric device is shown at *B*, and consists of a special form of

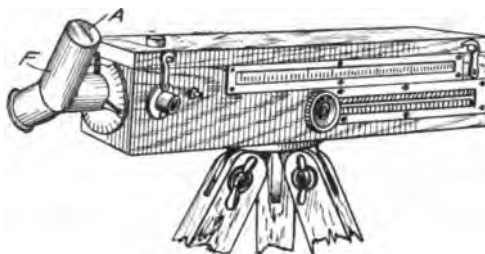


Fig. 75. Universal Photometer.

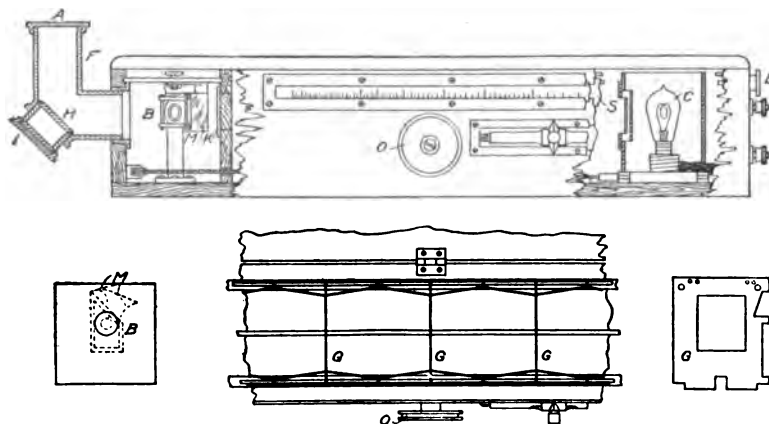


Fig. 76. Sectional View of Universal Photometer.

Lummer-Brodhun optical screen. A standardized incandescent lamp *C* is used as the photometric standard and this may be connected to a battery, or be adapted to use on the mains supplying the lamps in the room where measurements are to be taken. All stray light is carefully screened from the interior of the box by a series of screens *G*. The instrument scale is calibrated in foot-candles and in candle-powers.

When illumination is to be measured, a specially selected translucent screen is placed at *A* and the illumination of this plate, which is placed at the point and in the plane where the value of the illumination is desired, is reflected to the photometric device by the mirror at *H*. A second plate *K* is mounted so as to be illuminated by the standard lamp and the photometer is balanced by making the illumination of *A* and *K* the same. When the intensity of a light source is to be determined, the screen at *A* is replaced by a small aperture and a diffusing surface *I* is put in place of the mirror *H*. The illumination of *I* is now compared with the illumination of *K*, and when the two are made equal, the photometer reads the candle-power of the light source, or some multiple of this candle-power. The range of this instrument is increased by the use of suitably arranged absorbing screens which may be readily inserted or removed, and as ordinarily equipped, the range in foot-candles is approximately from .004 to 2,000. The variety of uses which can be made of such a photometer is large, and some idea of its portability can be obtained from the dimensions of the box, 24" x 4½" x 5", and its weight, fully equipped, of 8 pounds. It is very accurate considering its compactness.

Integrating Photometers. *Matthews.* This photometer is used to some extent and a very good idea of its construction can be obtained from Fig. 77. By means of a system of mirrors, the light given by the lamp in several directions may be integrated and thrown on the photometer screen for comparison with the standard, the result giving the mean spherical candle-power from one reading. By covering all but one pair of screens, the light given in any one direction is easily determined.

Another type of integrating photometer is known as the *integrating sphere* or *globe photometer*. If a light source is placed within a sphere, the interior walls of which are coated with a white diffusing surface, the illumination of that surface at any point is due partly to the light falling on it directly, and partly to the light reflected from the remainder of the surface of the sphere. The reflected light is proportional to the total flux of light from the light source and so, if the direct light is screened from the point considered, its illumination is proportional to the total flux of light, and hence to the mean spherical candle-power of the light source.

The practical application of this principle is to so arrange our

properly coated sphere that the lamp to be tested may be readily inserted; to replace a small portion of the sphere by a piece of unpolished white glass; to shut off the direct rays of the lamp to be

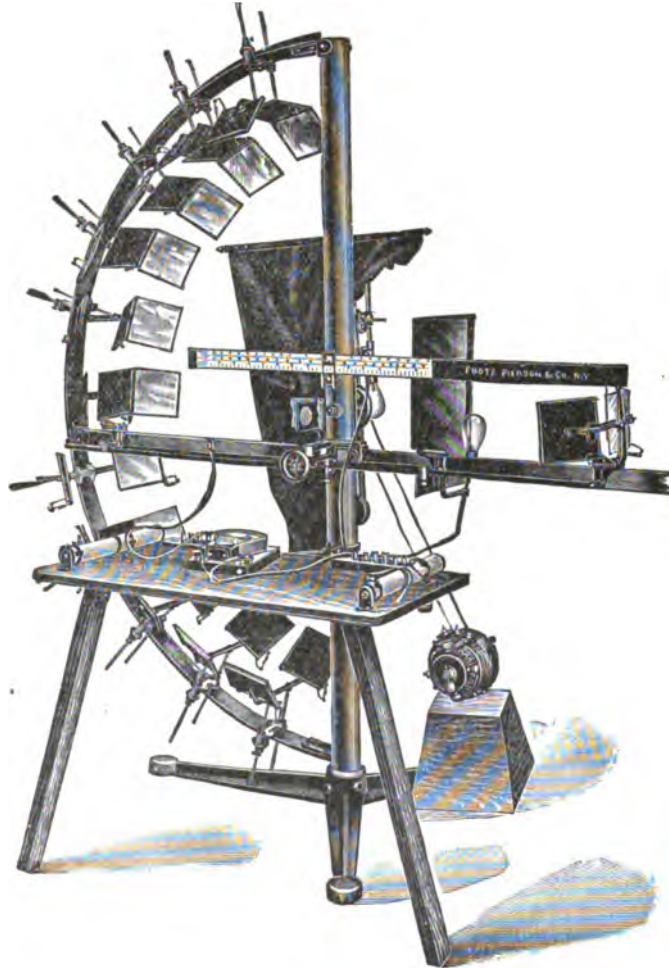


Fig. 77. Integrating Photometer.

measured from this glass surface; and to so mount a photometer screen and standard lamp that the illumination of the glass section can be measured. Under these conditions the illumination of the glass screen is proportional to the mean spherical candle-power of the lamp under test. A substitution method is used in practice. A

standardized lamp of the general type of the one to be tested is mounted in the sphere and the constant of the instrument for this type of lamp is determined. The unknown lamps are then put in place and their candle-power is readily determined, once the constant of the instrument is known. Figs. 78 and 79 give some views of the integrating

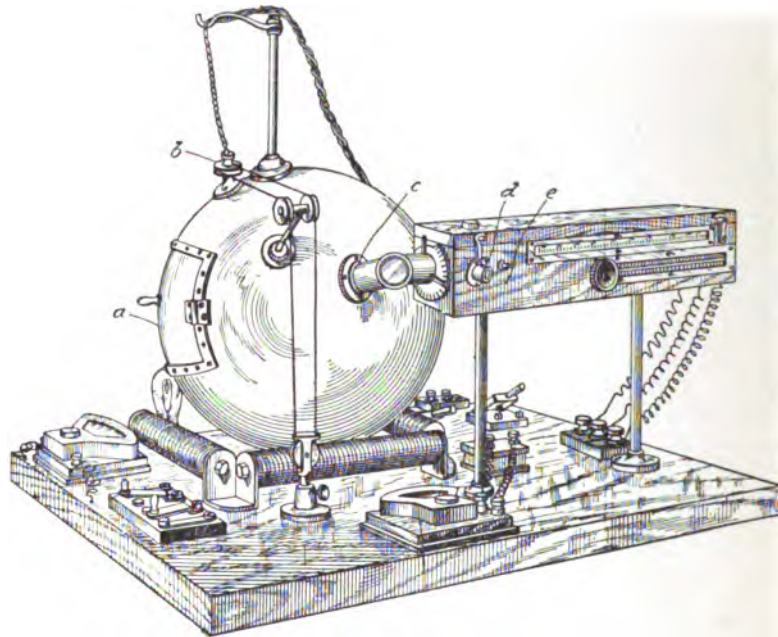


Fig. 78. Eighteen-Inch Integrating Sphere Equipped with Photometer.

sphere and indicate the range of the sizes in which it may be constructed.

INCANDESCENT LAMP PHOTOMETRY

Apparatus. Some sort of screen, either the Bunsen type or the Lummer-Brodhun screen preferred, should be mounted on a carriage moving on a suitable scale, and the lamp holders, one for the standard, the other for the lamp to be tested, are mounted at the ends of this scale. There are several types of so-called station photometers arranged so as to be very convenient for testing incandescent lamps. Fig. 80 shows one form of station photometer manufactured by Queen & Co. The controlling rheostats and shielding curtains are not shown here. Fig. 81 shows a form of portable photometer for

incandescent lamps. The length of scale should not be less than 100 centimeters, and 150 to 200 centimeters is preferred. This scale may be divided into centimeters or, for the purpose of doing away with much of the calculation, the scale may be a *proportional scale*. This scale is based on the law of inverse squares and reads the inverse ratio of the squares of the distances from the two lights being compared.

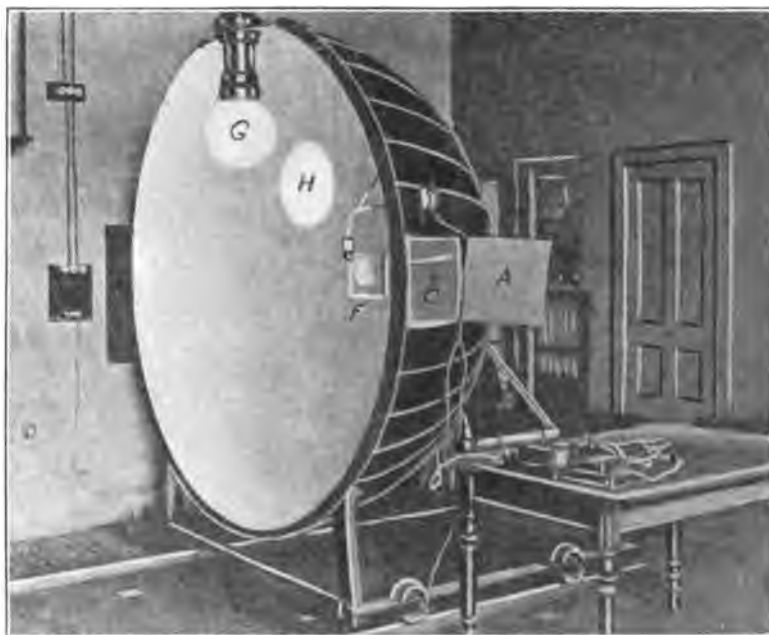


Fig. 79. Interior of 80-Inch Integrating Sphere.

If the standard used always has the same value, the scale may be made to read in candle-powers directly.

For mean horizontal candle-power measurements, the lamp should be rotated at 180 revolutions per minute, when mounted in a vertical position.

For distribution curves a universal lamp holder which will allow the lamp to be placed in any position, and which indicates this position, is used.

For mean spherical candle-power, the following method is used when the Matthews photometer is not available:

The lamp is placed in an adjustable holder and readings taken with the lamp in thirty-eight positions, as follows:

The measurement of the spherical intensity. For convenience the tip of the lamp and its base may be termed the north and south poles respectively.

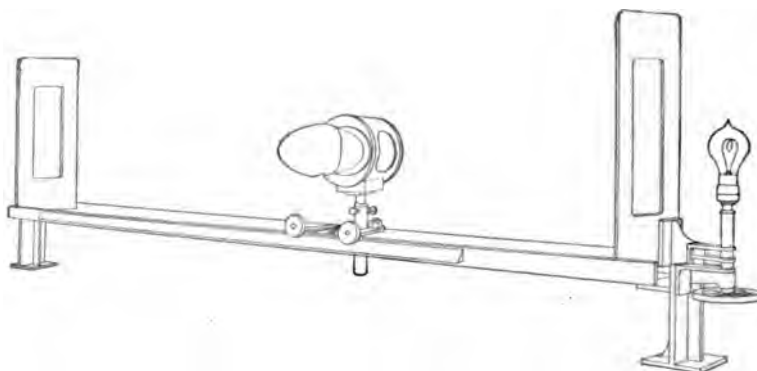


Fig. 80. Station Photometer.

The mean of 13 readings taken at intervals of 30° , is taken to give the mean horizontal candle-power.

Beginning again at 0° azimuth, thirteen readings are made in the prime meridian or vertical circle, the interval again being 30° , and the last reading checking the first.

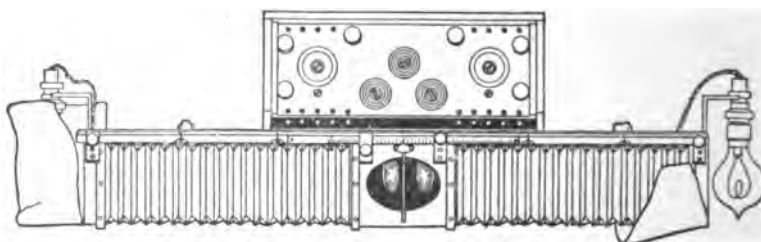


Fig. 81. Portable Photometer for Incandescent Lamps.

It will be noticed that four readings, two being check readings, have been made at 0° azimuth in each case. The mean of the four is taken as the *standard reading*, it being the value of the intensity, in this position, should the lamp be used as a standard.

Additional sets of thirteen readings each—the last reading checking the first one—are similarly made on each of the vertical circles through 45° , 90° , and 135° azimuth.

In combining the readings for the mean spherical intensity, a note is taken of the repetitions.

Neglecting the repetitions, which may also be omitted in part, in the practice of the method, there remain thirty-eight points, as follows:

	DISTRIBUTED VALUES
The mean of four measurements at the north pole of the lamp.....	1
Four measurements on each of the vertical circles through 0° and 90° azimuth at vertical circle readings of 60°, 120°, 240°, and 300°....	8
Four measurements on each of the vertical circles through 0°, 45°, 90°, and 135° azimuth at vertical circle readings of 30°, 150°, 210°, and 330°.....	16
Twelve measurements 30° apart at the equator.....	12
Four null values at the south pole of lamp.....	1
Total number of effective measurements.....	38

The points thus laid off on the reference sphere are approximately equidistant, being somewhat closer together at the equator than at the poles.

When the lamp is rotated, readings are taken for each 15° or 30° in inclination, from 0° to 90°, and from 0° to 270°. These are integrated values for their corresponding parallels of latitude on the unit sphere.

The mean spherical candle-power from these readings may best be obtained by plotting a distribution curve from the readings, determining the area of this closed curve by means of a planimeter and taking the radius of an equivalent circle as the value for the mean spherical candle-power.

The *Rousseau diagram* may be used for determining the mean spherical candle-power of a lamp when its vertical distribution curve is known. Fig. 82 shows such a diagram made up for a *gem lamp* with a bowl reflector. Where the horizontal distribution curve of the lamp is not uniform the values for the vertical distribution curve should be taken with the lamp rotating so as to give average values at each angle. One-half of the distribution curve is drawn to scale *A* and a circle *B* is drawn with the source of light *O* as a center. Radii *C* are drawn at equal angles about the light source and extended until they intersect the circle *B*. The points of intersection of these lines with the circle are projected upon the straight line *D E*. Distances from this line are laid off on the verticals *F* equal to the distances from the center of the circle to the points where the corresponding radii cut the distribution curve. The area enclosed between the straight line *D E* and a curve drawn through the points just determined, *G H*, divided by the base line, is equal to the mean spherical

candle-power of the lamp. If the mean candle-power of the lamp within a certain angle is desired, it is only necessary to find the area of the diagram within the space indicated by that angle and divide by the corresponding base.

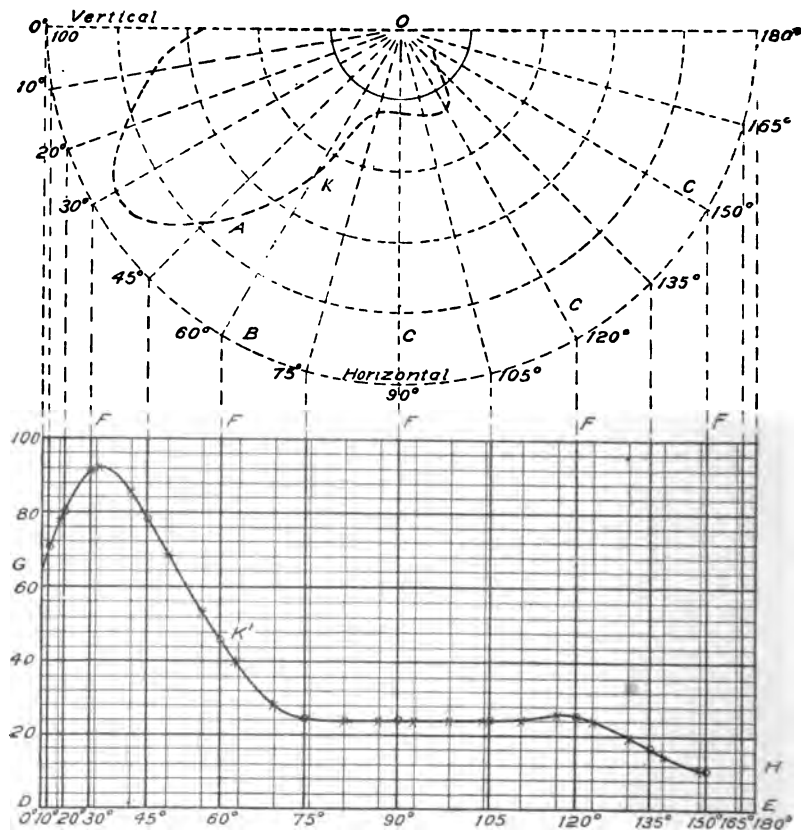


Fig. 82. Rousseau Diagram for Gem Lamp with Bowl Reflector.

In all tests the voltage of the lamp must be very closely regulated. A storage battery forms the ideal source of current for such purposes. In testing incandescent lamps, a standard similar to the lamp being tested is desirable and it should, preferably, be connected to the same leads. Any variation in the voltage of the mains then affects both lamps and the error introduced is slight.

ARC LIGHT PHOTOMETRY

Owing to the variation of the amount of light given out by an arc lamp in one direction at any time, due to variation of the qualities of the carbons, position of the arc, and also on account of the color of the light, etc., the photometry of arc lamps is much more difficult than that of incandescent lamps. The curves shown in Figs. 33 and 34 are average distribution curves taken from several lamps and will vary considerably for any one lamp. If the arc is enclosed, this variation is not so great.

The working standard should be an incandescent lamp run at a voltage above the normal so that the quality of the light will compare favorably with that of the arc. Since an incandescent lamp deteriorates rapidly when run at over voltage, the standard can be used only for short intervals and must be frequently checked.

Since an arc lamp can be mounted in one position only, mirrors must be used to obtain distribution curves. A mirror is used mounted at 45° with the axis of the photometer, and arranged so as to reflect the arc when in different positions. A mirror absorbs a certain per cent of the light falling upon it and this percentage must be determined by using lamps previously standardized. The length of the photometer bar must include the distance from the mirror to the arc.

The Weber photometer is well adapted to arc-light measurements inasmuch as appropriate screens may be used to cut down the intensity of the light.

A special form of the Matthews photometer is also used for testing arc lamps.

For the comparison of the illumination from arc lamps as installed in service, an instrument known as an *illuminometer* is sometimes used. This consists of a light wooden box, readily portable, having a black interior and arranged with two openings. One of these openings is for the purpose of admitting light from the source being considered, to a printed card. The other opening is for the purpose of viewing this card when illuminated by the light source. The printing on the card is made up from type of different sizes, and the smallest size which is legible, together with the distance from the light source, is noted. Another method of application is to select some definite size of type and then to move the instrument from the

light source to a point where this type is just legible and note the distance. From similar measurements taken on different lamps a good comparison may be obtained. Such an instrument is very convenient to use, and results obtained by different observers check very closely.

The *flicker photometer* is used for the comparison of different colored lights, the basis for comparison being that each light, though different in color, shall produce light sensations equally intense for the purpose of distinguishing outlines. It consists, in one form, of an arrangement by means of which a sectored disk is rotated in front of each light source, these disks being so arranged that the light from one source is cut off while the other falls on the screen, and *vice versa*, any form of screen being used for making the comparison. The disks must be revolved at such a rate that the light, viewed from the opposite side, will appear continuous. When the illumination of the two sides of the screen, under these conditions, is not the same, there will be a perceptible flicker and the screen should be so adjusted that this flicker disappears. The value of the light source can then be calculated from the screen reading in the usual manner. Another device consists of the use of a special lens mounted in front of a wedge-shaped screen, the lens being constructed so as to reverse the image of the two sides of the screen, as viewed by the eye, when such lens is in front of the screen. The lens is so mounted that it can be oscillated rapidly in front of the screen, giving the same result as would be obtained were it possible to reverse the screen at such a rapid rate as to cause the illumination on the two sides to appear continuous. The setting of this screen is accomplished as with the more simple forms.

Still another flicker photometer, the Simmance-Abady, makes use of a rotating wheel. This wheel is made of a white material having a diffusing surface, and its edge is so beveled that during part of a revolution a surface illuminated by one of the light sources is viewed through the eye-piece of the instrument, and during the other part of the revolution a surface viewed by the second light source is observed. The flicker occasioned by this change disappears when the screen is brought to a point where it is equally illuminated by the two light sources.

By the use of such forms of photometers it is found that results with different colored lights can be obtained, which are comparable with results obtained with lights of the same color.

REVIEW QUESTIONS.

PRACTICAL TEST QUESTIONS.

In the foregoing sections of this Cyclopedia numerous illustrative examples are worked out in detail in order to show the application of the various methods and principles. Accompanying these are examples for practice which will aid the reader in fixing the principles in mind.

In the following pages are given a large number of test questions and problems which afford a valuable means of testing the reader's knowledge of the subjects treated. They will be found excellent practice for those preparing for Civil Service Examinations. In some cases numerical answers are given as a further aid in this work.

REVIEW QUESTIONS
ON THE SUBJECT OF
DYNAMO-ELECTRIC MACHINERY

PART I

1. Explain briefly the two different methods of distributing electrical power.

2. (a) Why does the series characteristic curve bend over and the voltage begin to decrease when the current is large? (b) Explain why the E. M. F. of a series dynamo decreases very rapidly from about two-thirds its maximum value upon decreasing the current. (c) Draw a diagram of the circuit of a series dynamo.

3. (a) Why is the voltage of a shunt dynamo at its maximum an open circuit? (b) Why does the voltage of a shunt dynamo decrease when the load is increased? (c) Draw a diagram of the circuit of a shunt dynamo.

4. (a) What is the general form of the characteristic of a compound dynamo? (b) What is the difference between a long shunt compound-wound dynamo and a short shunt compound-wound dynamo? (c) Draw a diagram of the circuit of a short shunt compound machine.

5. What values of E. M. F. and current are used in plotting the external, internal and total characteristics of the shunt dynamo?

6. How does the construction of shunt coils differ from that of series coils?

7. (a) Why does sparking occur if the position of the brushes is such that the short-circuited coils generate no E. M. F.? (b) What is the correct position of the brushes for sparkless running?

8. Why should not the current pass through the springs which are used to give the brushes proper pressure upon the commutator?

DYNAMO-ELECTRIC MACHINERY

9. Explain why armatures need to be very carefully balanced.
10. Give the advantages of carbon brushes, and state why they are especially useful for high potential machines.
11. Explain why the resistance of the field coils of a shunt dynamo is calculated so low as to require a resistance rheostat to be placed in series with it.
12. What are the general tests which should be made upon a dynamo?
13. (a) Name the best conductors of magnetism. (b) How does the reluctivity of air compare with that of copper, brass, wood, etc.?
14. Upon what does the value of the magnetic flux in a magnetic circuit depend?
15. How does the residual magnetism of a dynamo affect the characteristic curve?
16. (a) What features are important in the construction of a good commutator? (b) How should a commutator be cared for in order to secure good running?
17. Name the precautions that should be taken when installing dynamos.
18. Referring to the electric circuit we have the terms — electric flux, electromotive force and resistance. What are the corresponding terms for the magnetic circuit?
19. What are the causes of sparking at the commutator?
20. How does a ring-wound armature differ from a drum-wound armature?
21. (a) Explain the effect of the series coil of a compound dynamo. (b) Explain why both shunt and series coils are required to make a dynamo self-regulating. (c) What is the effect if the series coil does not have enough turns? (d) What is the effect if the series coil has too many turns?
22. State the special advantages of a toothed armature core.
23. (a) Name the magnetic density per square inch usually allowed for field magnets of cast iron. (b) Of wrought iron (c) Of cast steel.
24. (a) What are horse-power curves? (b) What are resistance lines?

REVIEW QUESTIONS
ON THE SUBJECT OF
DIRECT-CURRENT MOTORS

1. State briefly the fundamental principle of the motor.
2. What is meant by the *torque* of a motor? How is it related to the power? If the field and armature current are constant, how is the torque related to the speed?
3. If the output of a motor is 60 horse-power, and the armature makes 490 revolutions per minute, what is the torque?
4. If the pulley of the motor in the preceding question is 22 inches in diameter, what is the effective pull upon the belt?
5. What is the commercial efficiency of a 500-volt motor which takes 120 amperes and delivers 71.6 horse-power?
6. What is meant by the counter-electromotive force of a motor? What relation does it bear to the efficiency?
7. The current in the armature of a shunt motor is 50 amperes; and the E.M.F. at the brushes, 240 volts. If the armature resistance is 0.38 ohm, what is the counter-E.M.F.?
8. Upon what does the speed of a motor depend?
9. Explain briefly the different methods used to vary the speed of shunt motors.
10. What disadvantages are there in controlling the speed of a shunt motor by a rheostat in the armature circuit?
11. A 230-volt shunt motor takes 55 amperes at full load, the speed being 760 revolutions per minute. What resistance must be inserted into the armature circuit to give half the full-load torque at two-thirds speed? How many watts are lost in this resistance under these conditions?
12. A shunt generator is to be used as a motor. What changes are necessary? Should the brushes be shifted, and, if so, to what point?

REVIEW QUESTIONS
ON THE SUBJECT OF
MANAGEMENT OF DYNAMO-ELECTRIC
MACHINERY.

PART I.

1. Why is the steam turbine well adapted for direct connection?
2. On a three-wire system is it better to use 110-volt or 220-volt motors? Explain why.
3. Describe construction and operation of the Fort Wayne self-starting synchronous motor.
4. What methods are used for controlling the speed of induction motors? Which one is preferable?
5. How can the friction of brushes and bearings be tested roughly?
6. What points should be considered in the selection of a machine?
7. Give a sketch of the connections of a compound-wound motor.
8. What is the advantage of a synchronous motor when its field is over excited? Explain.
9. Give a safe rule to follow for personal protection when handling electrical circuits of a sufficiently high voltage to be dangerous.
10. What precautions must be taken in fixing a direct-connected set?
11. Why should starting boxes always be furnished with direct-current motors?
12. (a) How are small induction motors started? (b) Why cannot large sizes be started in the same way?
13. If a machine is to be taken apart for the purpose of cleaning or inspecting it, what precautions should be taken?
14. Describe the method of lacing a belt.

REVIEW QUESTIONS
ON THE SUBJECT OF
ELECTRIC WIRING

1. Explain the three-wire system of wiring.
2. In case a test shows excessive leakage, or a ground or short circuit, how would you locate the trouble and remedy it?
3. Describe the construction and use of outlet-boxes.
4. What is the principal difference between alternating and direct-current circuits, so far as concerns the wiring system?
5. Compare the advantages of the two-wire and three-wire systems of wiring.
6. Under what general heads are approved methods of wiring classified?
7. A single-phase induction motor is to be supplied with 25 amperes at 220 volts; alternations 12,000 per minute; power factor .8. The transformer is 200 feet from the motor, the line consisting of No. 4 wire, 9 inches between centers of conductors. The transformer reduces in the ratio $\frac{2,500}{250}$, has a capacity of 30 amperes at 220 volts, and, when delivering this current and voltage, has a resistance-E. M. F. of 2.5 per cent, and a reactance E. M. F. of 5 per cent. Calculate the drop. (Use table and chart.)
8. What are the distinctive features of the different kinds of metal conduit?
9. Suppose power to be delivered, 300 K. W.; E. M. F. to be delivered, 2,200 volts; distance of transmission, 15,000 feet; size of wire, No. 00; distance between wires, 24 inches; power factor of load, .7; frequency, 100 cycles per second. Calculate line loss and drop in per cent of E. M. F. delivered. (Use table and chart.)
10. In installing A. C. circuits, what requirements are insisted on as to the placing of conductors in conduits?
11. Describe the manufacture, use, and special advantages of the different kinds of armored cable.

REVIEW QUESTIONS

ON THE SUBJECT OF

ELECTRIC LIGHTING

1. Define what is ordinarily meant by the term *efficiency of an incandescent lamp*, and give the values accepted at present for the efficiency of the carbon, gem, tantalum, and tungsten types.
2. What are the essential features of the Nernst lamp? Why is the ballast necessary?
3. What use is made of the flicker photometer?
4. How may the color of the flaming arc lamp be changed? With what color of light is the efficiency of this lamp the highest?
5. What is the object of shades and reflectors?
6. Describe the globe photometer and give its use.
7. What is the relation between the *hefner* and the *candle-power*?
8. What do you understand by the term *indirect lighting*?
9. Give your understanding of the Rousseau diagram and its use.
10. Name the advantages and disadvantages of the mercury vapor lamp and outline the two methods used in starting this type of lamp.
11. Explain the terms *mean spherical candle-power*; *mean hemispherical candle-power*; *mean horizontal candle-power*.
12. Define a *lumen*; a *foot-candle*.
13. In what way does the treatment of the filament of the gem lamp differ from that of the ordinary carbon filament?
14. Why are enclosed arc lamps preferable to open arcs? What is the approximate difference in the voltage at the terminals of these two types of lamps when connected in series circuits?
15. What use is made of the mercury arc rectifier in connection with lighting?

GENERAL INDEX

In this index the *Volume number* appears in Roman numerals—thus, I, II, III, IV, etc., and the *Page number* in Arabic numerals—thus, 1, 2, 3, 4, etc. For example, Volume IV, Page 327, is written IV, 327.

In addition to this "General Index," the reader is referred to the more exhaustive analytical index to be found in each volume.

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